TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

THESIS NO: 072/MSI/620

Design and Analysis of Dual Band Microstrip Antenna with Fractal Swastika Slot using Genetic Algorithm

by

Suroj Burlakoti

A THESIS

SUBMITTED TO THE DEPARTMENT OF ELECTRONICS AND COMPUTER ENGINEERING IN PARTIAL FULFULLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN INFORMATION AND COMMUNICATION ENGINEERING

DEPARTMENT OF ELECTRONICS AND COMPUTER ENGINEERING

LALITPUR, NEPAL

NOVEMBER, 2017

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The undersigned certify that it has been read and recommended to the Department of Electronics and Computer Engineering for acceptance, a report of thesis entitled **"Design and Analysis of Dual Band Microstrip Antenna with Fractal Swastika Slot using Genetic Algorithm"**, submitted by **Mr. Suroj Burlakoti** in partial fulfillment of the requirement for the award of the degree of **"Master of Science in Information and Communication Engineering"**.

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DEPARTMENTAL ACCEPTANCE

The thesis entitled **"Design and Analysis of Dual Band Microstrip Antenna with Fractal Swastika Slot using Genetic Algorithm"**, submitted by **Mr. Suroj Burlakoti** in partial fulfillment of the requirement for the award of the degree of **"Master of Science in Information and Communication Engineering"** has been accepted as a bonafide record of work independently carried out by him in the department.

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ACKNOWLEDGEMENT

I am very much thankful to my supervisor Dr. Surendra Shrestha who is a special candidate of my sincere gratitude because of his continuous supervision and guidance. I would like to convey my deep gratitude to our program coordinator Dr. Bashant Joshi for inspiration and support to carry out this thesis. I am highly indebted to Dr. Nanda Bikram Adhikari for his valuable guidance and advice during this thesis work. A special thank goes to head of department Dr. Dibakar Raj Pant for his precious support and motivations. My sincere gratitude also goes to Dr. Ram Krishna Maharjan, Dr. Sanjeev Prasad Pandey and Prof. Dr. Subarna Shakya for inspiring me through the research of the thesis with valuable knowledge and experience.

Finally, we would like to thank all the members of Department of Electronics and Computer Engineering, Pulchowk Campus, my colleagues and well-wishers who inspired and supported on the decision making process of this project.

ABSTRACT

Microstrip antennas are low profile, simple, inexpensive and versatile enough to cover many LTE bands as well as WiMAX, Bluetooth and WLAN. Fractal swastika slot is introduced to rectangular patch to improve the performance of antenna and make operational for multiple frequency band. The return loss of antenna is optimized by varying the slot size using genetic algorithm. The dual band microstrip patch antenna with fractal swastika slot is designed and simulated in High frequency Structural simulator (HFSS) software. As a result, the optimized length L and thickness D of slot size are 8 mm and 0.42 mm respectively. The designed antenna can be operated at the frequency of 2.4 GHz and 4.7 GHz. The results shows that the performances of purposed antenna are improved in terms of return loss, VSWR, bandwidth and gain whose values are -20.16 dB, 1.21, 140MHz and 1.74 dBi respectively for resonance frequency 2.4 GHz and -20.61 dB, 1.20, 240 MHz and 2.4dBi respectively for resonance frequency 4.7 GHz. Whereas the return loss, VSWR, bandwidth and gain of reference antenna are -14.14 dB, 1.45, 80 MHz, 1.38 dBi at resonance frequency 2.4 GHz and that of -13.03 dB, 1.57, 160 MHz and 0.87 dBi. The return loss is improved by 37%, VSWR is reduced by 0.24, bandwidth is increased by 50% and gain is improved by 26 % as compared to the reference antenna. The effect of changing slot size is also observed and formulated. The purposed antenna can be applicable for different wireless applications near around 2300-2500 MHz and 4600-.4900 MHz frequency bands.

Keywords: Microstrip antenna, Fractal swastika slot, Dual-band antenna, Return loss, Bandwidth

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LIST OF ABBREVIATIONS

CAD	Computer Aided Design
CST	Computer Simulation Technology
dB	Decibel
FR4	Flame Retardant 4
GA	Genetic Algorithm
GHz	Giga-Hertz
HFFS	High Frequency Structural Simulator
IEEE	Institute of Electrical and Electronics Engineers
IMT	International Mobile Telecommunication
ISM	Industrial, Scientific and Medical
LAN	Local Area Network
LTE	Long Term Evolution
MATLAB	Matrix Laboratory
MMIC	Microwave Monolithic Integrated Circuit
NN	Neural Network
PSO	Particle Swam Optimization
RF	Radio Frequency
RFID	Radio Frequency Identification
VSWR	Voltage Standing Wave Ratio
Wi-Fi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network

1. INTRODUCTION

1.1 Background

The need for light weight and miniature size antenna has become a mandatory requirement in recent world because of the advancement in wireless communication technology. The most popular antenna in this category is microstrip patch antenna. These antenna consist of a flat rectangular sheet or "patch" of metal, mounted over a larger sheet of metal called as ground plane [1]. Microstrip antenna are low profile, comfortable to planar and non-planar surfaces, simple and inexpensive to manufacture using modern printed-circuit technology, mechanically robust when mounted on rigid surfaces, compatible with Microwave Monolithic Integrated circuit (MMIC) designs, and when the particular patch shape and mode are selected, they are very versatile in terms of resonant frequency, polarization pattern, and impedance [2]. The development of antenna for wireless communication also requires an antenna with more than one operating frequencies. This is due to many reasons, mainly because there are various wireless communication systems and many telecommunication operators using various frequencies. It is versatile enough to cover many LTE bands as well as WiMAX, Bluetooth and WLAN [3].

A slot antenna consists of a metal surface, usually a flat plate, with one or more holes or slots cut out. The shape and size of the slot, as well as the driving frequency, determine the radiation pattern. Microstrip Patch Antenna using different slots helps in reduction of return loss as well as increase of bandwidth significantly. Also dual slots have low return loss and VSWR at low operating frequency as compare to single slot and having no slot.

The operating band of an antenna depends on several factors; one of which is antenna shape. There are many shapes widely used for designing antenna. Another example is antenna designed using fractals which are called fractal antenna. Fractals are shapes with a property called “self-similarity property” [4]. This means that parts of the whole structures of fractals are similar to the whole structure. Because of their self-similarity property, the fractal structure of fractals is resonant at multi frequencies. Hence, fractal antenna can be operated at multi-frequency bands. Here swastika slot fractal antenna is purposed.

The Genetic Algorithm method is based on the Darwinian principle of survival of the fittest. GA optimizer procedure, it begins by produce arbitrarily scattered primary population. Later than the primary population is formed and fitness value assign to each member of the population, a reproductive circle, consisting of a collection, crossover, and mutation operator, are performed until an adequate amount of new individuals are generated to fill new production. When new generation has been entirely filled, it replaces the older generation and, if the termination condition has not been met, a new round of selection, crossover, and mutation begins [5].

1.2 Problem Statement

Conventional antenna operating at low frequency such as dipoles and rectangular patch antenna tend to be physically large and have a single operating band because the size and shape of an antenna dominantly affect its operating frequency. Basic geometries of these antenna suffer from a small bandwidth, which is of the order of a few percent of the operational frequency. In order to increase the rate of data transfer, modern wireless system designs require increased antenna bandwidth that these geometries can handle.

1.3 Objectives

The general objective of this project is to design and analysis the performances of dual band microstrip patch antenna with swastika shaped fractal slot for wireless applications. Specific objectives are:

- To design and optimize dual band microstrip antenna with fractal swastika shaped slot using simulation.
- To analyze and compare the performance of fractal swastika slot antenna with rectangular shaped microstrip patch antenna.

2. LITERATURE REVIEW

For reception and transmission of electromagnetic signal, antenna is essential part. Microstrip patch antenna is one of the most promoted antenna structure due to its various convenient use and low profile. This antenna are more acceptable for their special feature that they can be directly printed in circuit board. It has various application in wireless communication such as mobile communication, radar application, broadcast television, RFID and in satellite communication etc. [6].

The dual-band patch antenna with Peano-Gosper fractal curve slot mounted on a patch antenna was designed [4]. The dimensions of the slot on a patch antenna are optimized using particle swarm optimization (PSO) by varying the width of Peano-Gosper fractal curve slot (W) and the thickness of the slot (D). The optimized width W and thickness D are equal to 24 mm and 0.12 mm, respectively and the designed antenna can be operated at the frequency of 2.45 GHz and 5 GHz.

Particle swarm optimization (PSO) method was used to design of a dual-band patch antenna using IE3D [7]. The method effectively obtains the geometric parameters for efficient antenna performance. Maximum return loss obtained at 2.4 GHz is -43.95 dB and at 3.08 GHz is -27.4dB. Its bandwidth of 33.54 MHz ranges from 2.38355 GHz to 2.41709 GHz.

A particle swarm optimization based algorithm have been developed to decide the patch dimensions of dual band square stacked patch antenna (SPA) operating in the X/Ku band [8].The cost function for the PSO is evaluated with the help of trained neural network (NN) to reduce the lengthy simulation time. The results from this PSO based CAD model have been cross verified with the experimental results for some typical stacked patch antenna.

The radiation pattern synthesis for retro directive arrays was studied for mobile communication services in a scenario using high altitude platforms [9]. For this purpose, a dual-band and dual-polarization microstrip antenna array has been designed, whereby the array should receive the signal in one band and resend it in the other operating band.

The radiation pattern in the receiving mode has been synthesized with the PSO algorithm, which allowed steering the major lobe and controlling the side lobe level.

Genetic algorithms are capable of handling a large number of design parameters and work for optimization problems that have discontinuous or non-differentiable multi-dimensional solution spaces, making them ideal for antenna optimization [5]. Genetic Algorithm optimization of bandwidth of a patch antenna is very important area of research. The standard fitness function for the GA program will be used for the analysis of the patch antenna.

The miniaturization of the patch antenna has become an important issue in reducing the volume of entire communication system. Genetic algorithm is used for size reduction of a microstrip antenna by M. Lamsalli [10]. The shape of a typical rectangular patch is modified in order to reduce it resonance frequency keeping the physical volume of the antenna constant. Indeed, the initial patch is divided into 10×10 small uniform rectangles (Pixel), and the genetic algorithm searches, the optimal configuration for the desired goal. The resonance frequency of a micro-strip patch is shifted from 4.9GHz to 2.16GHz and a rate of miniaturization is up to 82%. To validate the procedure, an antenna prototype has been fabricated and tested with an FR4 substrate.

3. RELATED THEORY

3.1 General structure of Microstrip Patch Antenna

A microstrip antenna generally consists of a dielectric substrate sandwiched between a radiating patch on the top and a ground plane on the other side [11] as shown in Figure 3.1. The patch is generally made of conducting material such as copper or gold and can take any possible shape. The radiating patch and the feed lines are usually photo etched on the dielectric substrate.

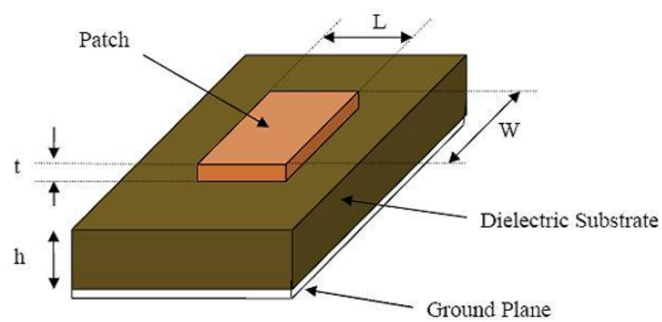


Figure 3.1: Structure of microstrip patch antenna

[Figure not in scale]

The patch is generally square, rectangular, circular, triangular, and elliptical or some other common shape. For a rectangular patch, the length L of the patch is usually in the range of $0.3333\ \lambda_0 < L < 0.5\ \lambda_0$, where λ_0 is the free space wavelength. The patch is selected to be very thin such that $t << \lambda_0$, where t is the patch thickness. The height of the substrate is usually $0.003\ \lambda_0 \leq h \leq 0.05\ \lambda_0$. The dielectric constant of the substrate ε is typically in the range $2.2 \leq \varepsilon \leq 12$ [13].

Microstrip antenna are used as embedded antenna in handheld wireless devices such as cellular phone, and also employed in Satellite communications. Microstrip antenna is light weight and low fabrication cost, supports both linear as well as circular polarization, can be easily integrated with microwave integrated circuits, capable of dual and triple frequency operations and mechanically robust when mounted on rigid surfaces.

Microstrip patch antenna suffer from more drawbacks as compared to conventional antenna such as narrow bandwidth, low efficiency and Gain, extraneous radiation from feeds and junctions, low power handling capacity and surface wave excitation.

3.3 Feeding Techniques of Microstrip Antenna

Microstrip patch antenna can be fed by a variety of methods such as microstrip line, coaxial probe, aperture coupling and proximity coupling feeding. These methods can be classified into two categories like contacting and non-contacting. In the contacting method, the RF power is fed directly to the radiating patch using a connecting element such as a microstrip line. In the non-contacting scheme, electromagnetic field coupling is done to transfer power between the microstrip line and the radiating patch. The four most popular feed techniques [14] used are the microstrip line, coaxial probe, aperture coupling and proximity coupling. Microstrip line feed is used.

In Microstrip Line feeding technique, a conducting strip is connected directly to the edge of the microstrip patch as shown in Figure 3.2. The conducting strip is smaller in width as compared to the patch. This kind of feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure.

An inset cut can be incorporated into the patch in order to obtain good impedance matching without the need for any additional matching element. This is achieved by properly controlling the inset position. Hence inset cut is an easy feeding technique, since it provides ease of fabrication and simplicity in modeling as well as impedance matching. However as the thickness of the dielectric substrate increases, surface waves and spurious feed radiation also increases, which hampers the bandwidth of the antenna, also results in undesirable cross polarization effects.

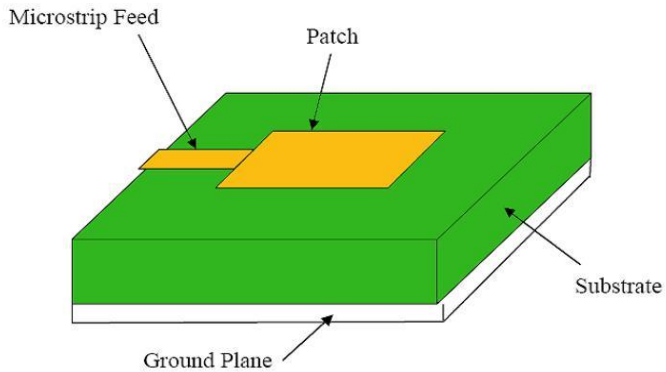


Figure 3.2: Microstrip Line Feed

[Figure not in scale]

3.4 Performance Parameters of Microstrip Patch Antenna

The performance of an antenna can be measured by a number of parameters such as Return Loss, Radiation Pattern, VSWR, Bandwidth, Gain, Directivity, Beam width and antenna efficiency etc.

3.4.1 Radiation Pattern

The antenna pattern is a graphical representation in three dimensional of the radiation of the antenna as the function of direction. It is a plot of the power radiated from an antenna per unit solid angle which gives the intensity of radiations from the antenna [15]. If the total power radiated by the isotropic antenna is P, then the power is spread over a sphere of radius r, so that the power density S at this distance in any direction is given as:

$$S = \frac{P}{4\pi r^2} \quad (3.1)$$

Then the radiation intensity for this isotropic antenna U_i can be written as:

$$U_i = \frac{P}{4\pi} \quad (3.2)$$

Isotropic antenna are not realizable in practice but can be used as a reference to compare the performance of practical antenna. The radiation pattern provides information on the antenna beam width, side lobes and antenna resolution to a large extent.

The Electric plane i.e. E plane pattern is a graphical representation of antenna radiation as a function of direction in a plane containing a radius vector from the center of the antenna to the point of maximum radiation and the electric field intensity vector. Similarly the Magnetic plane, H plane pattern can be drawn considering the magnetic field intensity vector.

3.4.2 Gain

Antenna gain is the ratio of maximum radiation intensity at the peak of main beam to the radiation intensity in the same direction which would be produced by an isotropic radiator having the same input power. Isotropic antenna is considered to have a gain of unity. The gain function can be described as:

$$G(\theta, \emptyset) = \frac{P(\theta,\emptyset)}{\frac{Wt}{4\pi}} \tag{3.3}$$

Where $P(\theta, \emptyset)$ is the power radiated per unit solid angle in the direction (θ, Ø), here θ and Ø indicate the dependence on directions from the antenna and Wt is the total radiated power.

Conventional microstrip antenna has poor radiation efficiency have poor gain. Numerous researches have been conducted in various parts of the world in order to obtain high gain antenna.

3.4.3 Directivity

When three dimensional antenna pattern is measured, the ratio of normalized power density at the peak of the main beam, P_{max} to the average power density, P_{avg} is called the directivity.

The directivity of the antenna is given by:

$$D = \frac{Pmax}{Pavg} \tag{3.4}$$

The relation between directivity and gain can be given as:

$$G = \eta D \text{ , where } \eta \text{ is the antenna efficiency} \quad (3.5)$$

3.4.4 Bandwidth

Bandwidth is defined as the range of usable frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard. The bandwidth can be the range of frequencies on either side of the center frequency where the antenna characteristics like input impedance, radiation pattern, beam width, polarization, side lobe level or gain, are close to those values which have been obtained at the center frequency. The bandwidth of narrow band and broadband antenna are defined as:

$$BW(Broadband) = \frac{Fh}{Fl} \quad (3.6)$$

$$BW(narrowband)\ \% = \frac{Fh-Fl}{Fc} * 100\% \quad (3.7)$$

Where *Fh* is the upper frequency, *Fl* is the lower frequency and *Fc* is the center frequency.

3.4.5 Return loss

Return loss or reflection loss is the reflection of signal power from the insertion of a device in a transmission line or optical fiber. It is expressed as ratio in dB relative to the transmitted signal power. The return loss is given by:

$$Return\ Loss\ (dB) = 10 \log \frac{Pr}{Pi} \quad (3.8)$$

Where Pi is the power supplied by the source and Pr is the power reflected.

Assume, *Vi* is the amplitude of the incident wave and *Vr* is that of the reflected wave, then the return loss can be expressed in terms of the reflection coefficient Γ as:

$$RL = -20 \log |\Gamma|, \quad (3.9)$$

The reflection coefficient Γ can be expressed as: $\Gamma = \frac{Vr}{Vi}$

The return loss should be less than -10 dB for an antenna to radiate effectively.

3.4.6 VSWR

A standing wave in a transmission line is a wave in which the distribution of current, voltage or field strength is formed by the superimposition of two waves of same frequency propagating in opposite direction. Then the voltage along the line produces a series of nodes and antinodes at fixed positions.

The total voltage on the line V (z) is given by,

$$V(z) = V^{+}e^{-j\beta z} + V^{-}e^{+j\beta z} \tag{3.10}$$

The Voltage Standing Wave Ratio (VSWR) can be defined as:

$$VSWR = \frac{Vmax}{Vmin} = \frac{1+|\Gamma|}{1-|\Gamma|} \tag{3.11}$$

The value of VSWR should be between 1 and 2 for efficient performance of an antenna.

3.5 Slot Antenna

A slot antenna consists of a metal surface, usually a flat plate, with one or more holes or slots cut out. When the plate is driven as an antenna by a driving frequency, the slot radiates electromagnetic waves in a way similar to a dipole antenna. The shape and size of the slot, as well as the driving frequency, determine the radiation pattern. Often the radio waves are provided by a waveguide, and the antenna consists of slots in the waveguide. Slot antenna are often used at UHF and microwave frequencies instead of line antenna when greater control of the radiation pattern is required. Slot antenna are widely used in radar antenna, for the sector antenna used for cell phone base stations, and are often found in standard desktop microwave sources used for research purposes. The advantages of slot antenna are its size, design simplicity, and convenient adaptation to mass production using either waveguide or PC board technology.

3.6 Fractal Slot Antenna

3.6.1 Fractals

Fractal is a rough or fragmented geometric shape that can be subdivided in parts, each of which is (at least approximately) a reduced/size copy of the whole. The expression "fractal" was found by the French mathematician B.B. Mandelbrot in 1970. A "fractal" is a geometrical shape that can be part into parts, each of which is a diminished size duplicate of the entire vastly. Fractals are a class of shapes which have not trademark size. Every fractal is made out of numerous cycles of a solitary shape. The emphasis can proceed interminably, in this manner framing a shape inside of a limited limit however of boundless length or region [16]. The utilization of fractal geometries are utilized as a part of numerous ranges of science and designing; one of which is receiving antenna. Radio antenna utilize some of these geometries for different correspondence applications. The utilization of fractal geometries has been appeared to enhance a few reception apparatus elements to shifting degrees. For decreasing the extent of radio wire, fractal geometries have been presented.

3.6.2 Fractal shaped antenna elements

The way of fractal geometries has gotten the consideration of radio wire fashioners, fundamentally as a past-time. However with the extending of comprehension of reception apparatuses utilizing them a few geometrical and radio wire highlights have been between connected. This has prompted the development of another class of reception apparatuses, called fractal molded radio wires. Cohen has attempted the helpfulness a few fractal geometries tentatively. Koch bends, Murkowski bends, Sierpinski gasket are among them. The initial few stages in the development of the Sierpinski gasket are appeared in Figure 3.3 (i) [17]. Next prevalent fractal is known as the Koch snowflake [18]. This fractal additionally begins as a strong equilateral triangle in the plane, as showed in of Figure 3.3 number of structures taking into account absolutely deterministic or arbitrary fractal trees has likewise turned out to be amazingly helpful in growing new outline procedures for reception apparatuses and recurrence particular surfaces. A sample of a deterministic tenary fractal tree is appeared in Figure 3.3 (iii). The Koch snowflakes and islands have been basically used to grow new outlines for scaled down circle and also in microstrip patch antenna. New outlines for scaled down dipole reception apparatuses have additionally been produced in light of an assortment of Koch bends and fractal trees.

The advantages of fractal antennas are smaller cross sectional area, no impedance matching network required, multiple resonances, and higher gain in some cases. Although in the early stage of their development, these antenna designs suffer from few disadvantages are fabrication and design is little complicated, lower gain in some cases and complexity to represent mathematically. Further investigations and new developments in this field may be helpful in overcoming these disadvantages.

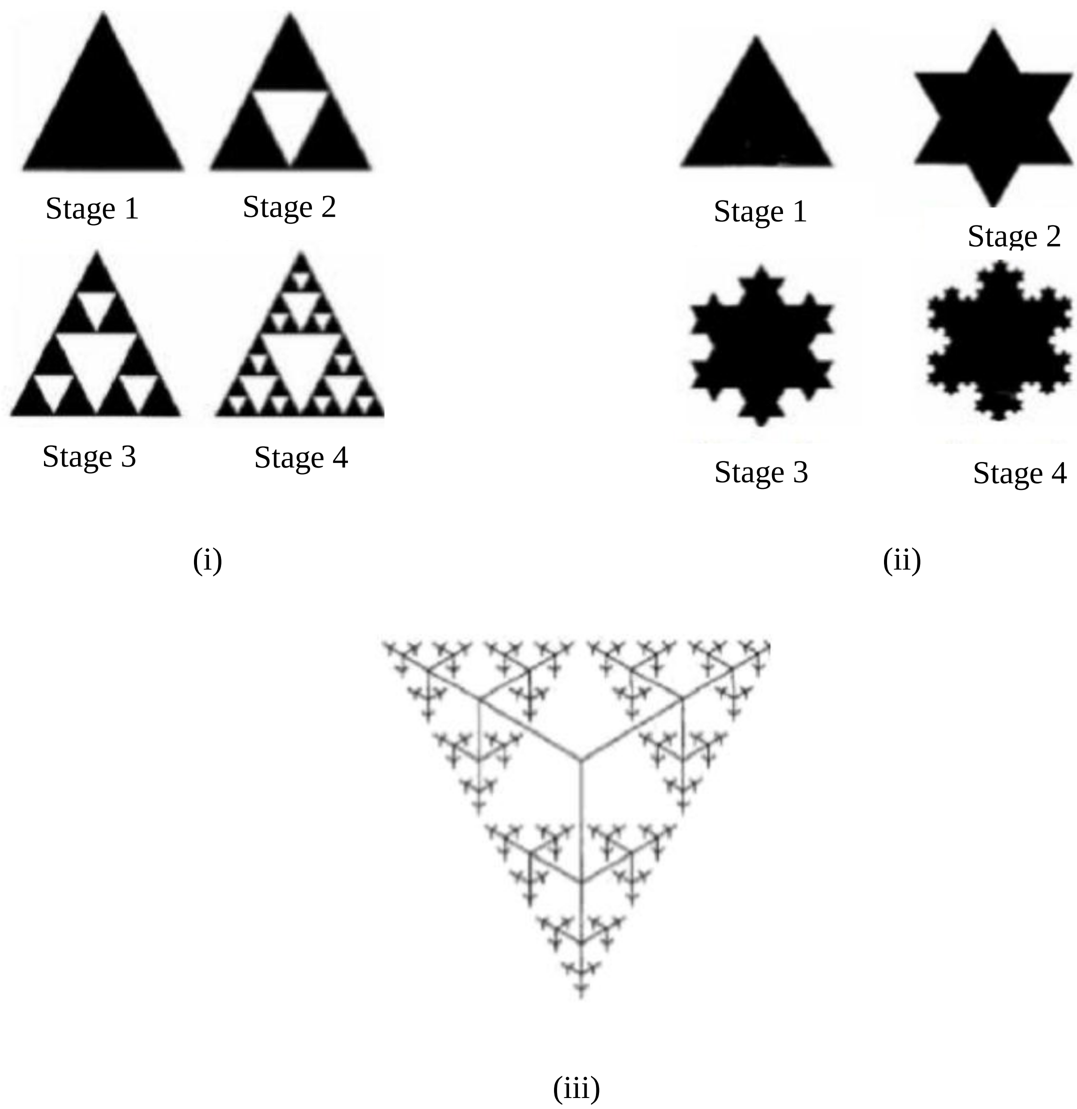


Figure 3.3: Different fractal shapes (i) Stages of Sierpinski Gasket Fractal (ii) Stages of Koch Fractal (iii) Stage of Ternary fractal

3.6.3 Fractal shaped slot

Microstrip antenna can be designed using different shaped slot. The generally used shapes of slot are stub slot, circular slot, triangular slot, L shaped slot etc. But the parameters of antenna can also be improved by using fractal shaped slot on it. The operating band of an antenna depends on several factors; one of which is antenna shape. There are many shapes widely used for designing antenna. The antenna designed using fractals which are called fractal antenna [19]. Fractals are shapes with a property called “self-similarity property”. Which means that some parts of the whole structures of fractals are similar to the whole structure. Because of their self-similarity property, the fractal structure of fractals is resonant at multi frequencies. Hence, fractal antenna can be operated at multi-frequency bands.

3.7 Genetic Algorithm

The concept of the GA, first formalized by Holland and extended to functional optimization, involves the use of optimization search strategies patterned after the Darwinian notion of natural selection and evolution [10]. During a GA optimization, the parameters of each individual of the population are usually encoded as a string of bits (chromosomes). The first group of individuals (generation) is created randomly. The fitness of each individual is determined by the cost function. Mating these individuals forms a new generation. The more fit individuals are selected and given greater chance of reproducing. Crossover and mutation are used to allow global exploration of the cost function. The best individual may be passed unchanged to the next generation. This iterative process creates successive generations until a stop criterion is reached. A block diagram of a simple genetic algorithm optimizer is presented in Figure 3.4.

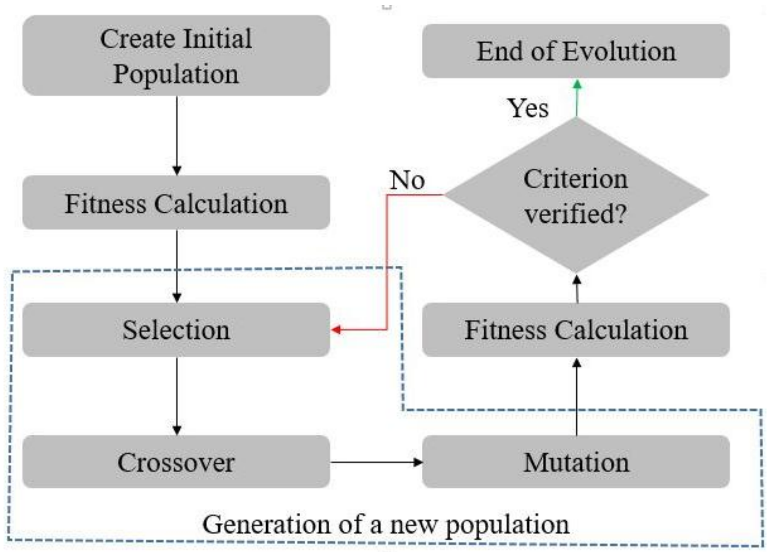


Figure 3.4: Steps involved in genetic algorithm

3.8 High Frequency Structural Simulator

High Frequency Structural Simulator (HFSS) is an interactive software package for calculating the electromagnetic behavior of a structure. The software includes post-processing commands for analyzing electromagnetic behavior in detail. Using HFSS, basic electromagnetic field quantities, characteristic port impedances and propagation constants and generalized S-parameters can be compute. It is used to draw the structure, specify material characteristics for each object, and identify ports and special surface characteristics. HFSS then generates the necessary field solutions and associated port characteristics and S-parameters for the structure designed.

HFSS uses a numerical technique called the Finite Element Method (FEM). This is a procedure where a structure is subdivided into many smaller subsections called finite elements. The finite elements used by HFSS are tetrahedra and the entire collection of tetrahedra is called a mesh. A solution is found for the fields within the finite elements, and these fields are interrelated so that Maxwell's equations are satisfied across inter-element boundaries. Once the field solution has been found, the generalized S-matrix solution is determined.

3.9 Wireless standard and their frequencies

The technologies and standards used in wireless application and their frequency band are shown in Table 3.1 [12].

Table 3.1 Various wireless standard and their frequencies

Wireless Applications		Frequency Band (MHz)	Bandwidth (MHz)
GSM	GSM 900	890-960	70
	GSM 1800	1710-1805	95
	GSM 1900	1850-1990	140
IMT		2300-2400	100
		2700-2900	200
		3400-4200	800
		4400-4900	500
WLAN		2400-2484	84
		5150-5350	200
		5725-5825	100
Bluetooth		2400-2500	100
WiMAX		2500-2690	190
		3400-3690	290
		5250-5850	600

4. METHODOLOGY

The swastika slot fractal dual band microstrip antenna is designed and simulated in software Ansoft HFSS 15.0. Starting with a microstrip patch, genetic algorithm optimization techniques will be applied using MATLAB to optimize the bandwidth of antenna. Finally swastika slot fractal dual band microstrip antenna will be analyzed and compared to reference rectangular microstrip patch antenna.

4.1 Antenna Design

To design a microstrip patch antenna with swastika fractal slot using GA, first of all simple dual band antenna is designed as reference antenna

4.1.1 Reference antenna

The reference antenna [4] is a rectangular patch antenna operating at 2.47 GHz and 4.8 GHz, an example obtained from antenna Ansoft HFSS. It consists of a rectangular copper patch on FR4 substrate with relative permittivity of 4.4. The substrate size is 63.3 mm × 121 mm × 1.6 mm as shown in Figure 4.1.

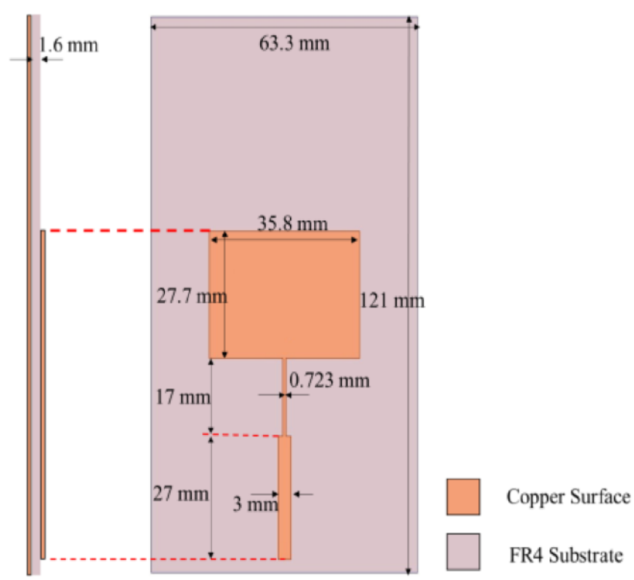
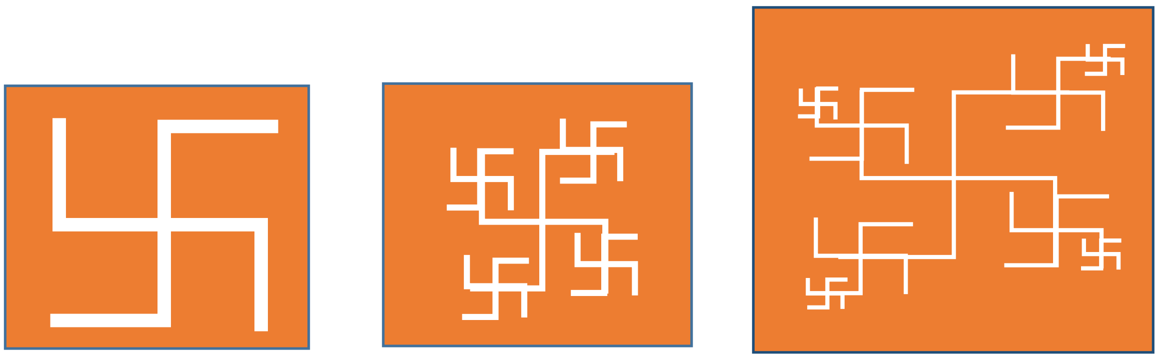


Figure 4.1: Design of Reference antenna

4.1.2 Dual band antenna with swastika fractal slot

The dual band antenna is designed by locating a slot with the stage 2 fractal swastika structure at the middle of rectangular patch of the reference antenna. The construction of the first three stages of fractal swastika slot is shown in Figure 4.2. The designed antenna shown in Figure 4.3 is optimized by varying the width W of fractal swastika and the width of slot D using GA subject to the condition that L is equal to W. The initial values of L and D will be taken as 18 mm and 0.5 mm, respectively.



(a) First stage (b) Second Stage (c) Third Stage

Figure 4.2: Fractal swastika slot

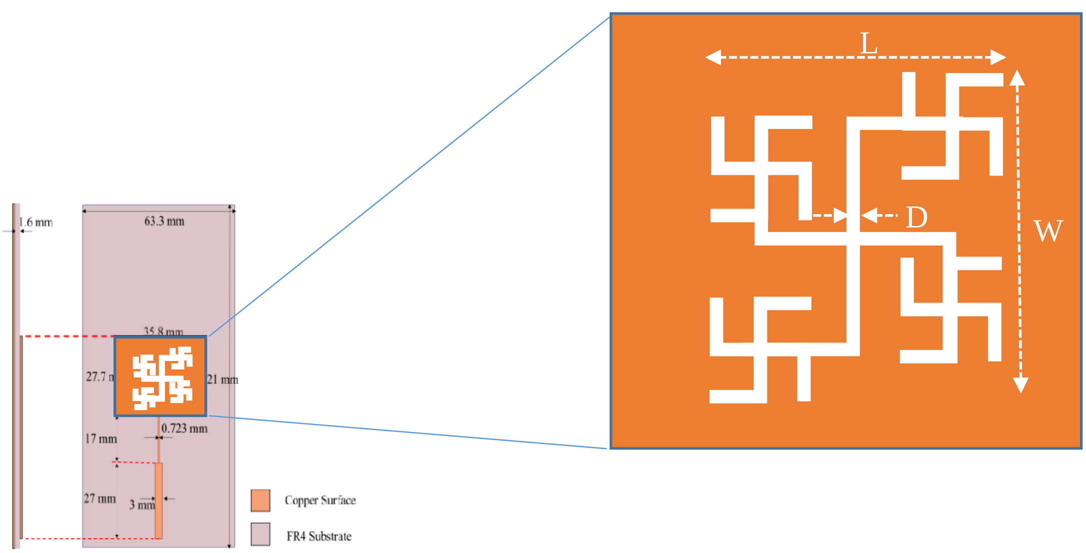


Figure 4.3: Design of Purposed antenna with fractal swastika slot

4.1.3 Formulation of swastika shape

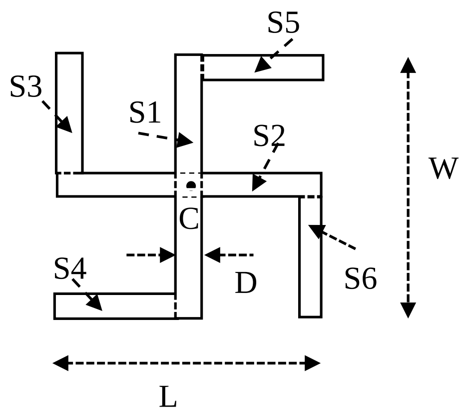
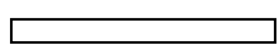
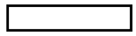
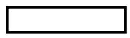


Figure 4.4 Structure of Swastika Shape

Here, L is length of swastika shape, W is width of swastika shape and D is thickness of swastika shape. S1, S2, S3, S4, S5 and S6 are the part of shape, combination of which made the whole swastika shape. C (cx, cy) is center of swastika shape. The position and size of different parts of swastika shape in reference with center position are shown in Table 4.1.

Table 4.1: Shape and size of different portion of swastika shape

Name of part	Shape	Size
S1		Position = [cx- D/2, cy-L/2] Dimension = D × L
S2		Position = [cx- L/2, cy-W/2] Dimension = L × D

S3		Position = [cx- L/2, cy-L/2] Dimension = (L-D)/2 × D
S4		Position = [cx- L/2, cy+D/2] Dimension = D × (L-D)/2
S5		Position = [cx+ L/2-D, cy-L/2] Dimension = D × (L-D)/2
S6		Position = [cx+D/2, cy+L/2-D] Dimension = (L-D)/2 × D

The total surface area A of swastika shape is given by the sum of area of all portion (S1, S2, S3, S4, S5, S6) minus area of S2 which is overlapped over S1.

$$A = 2 \times L \times D + 4 \times \frac{(L-D)}{2} \times D - D^2 \tag{4.1}$$

Solving Equation 4.1,

$$A = 4\,L\,D - 3\,D^2 \tag{4.2}$$

4.2 Optimization of antenna using Genetic Algorithm

Genetic Algorithm and the Swarm Intelligence are the two intelligent techniques currently using as a heuristic method for solving complex problem that are hard to find solutions using normal existing technique although these algorithms do not guarantee that it will always give optimal solution [20].

The objective of optimization is subject to the constraint that the return loss at the operating frequencies (2.4 GHz and 4.7 GHz) is less than -10 dB. The cost function for designing the antenna using GA [4] is shown in (4.3).

$$Cost\ function = \frac{Weight}{|S_{11,2.4GHz}+S_{11,4.7GHz}|} \tag{4.3}$$

Where $S_{11,\ 2.4GHz}$ and $S_{11,\ 4.7GHz}$ are the return loss at 2.4 GHz and 4.7 GHz, respectively and

$$Weight = \begin{cases} 0, & for\ S_{11,2.4GHz}\ and\ S_{11,4.7GHz} < -10 \\ 100, & otherwise \end{cases} \tag{4.4}$$

The initial values of slot length L and width D are taken as 18 mm and 0.5 mm as an initial population to optimize the value of return loss at 2.4 GHz and 4.7 GHz. The optimization is achieved at values of L and D of 8 mm and 0.42mm after 50 steps.

First the antenna is designed in HFSS simulation software using the initial values of slot dimension inserted to the reference antenna. Then the model is solved and values of s parameter observed after running the model. The fitness function is calculated using those parameters. Selection of best two parent chromosomes is done using roulette wheel selection mechanism. New offspring is created by using crossover probability of 0.7 for crossing over the parents. New offspring is mutated using mutation probability 0.01 by one point crossover. The algorithm is run using newly generated chromosomes to find the best chromosomes in multiple iterations.

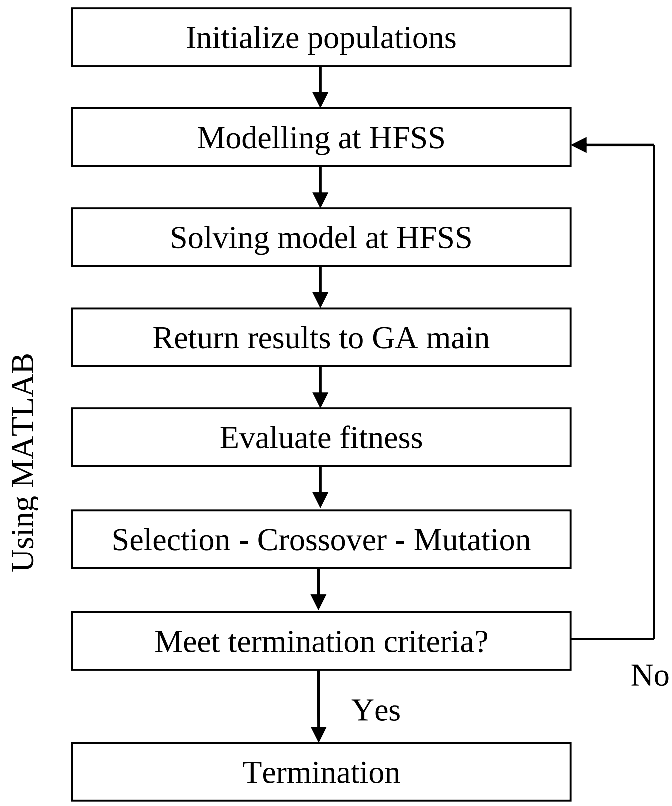


Figure 4.5: Flow diagram of Optimization Procedure

4.4 Performance analysis

The performance analysis of microstrip antenna are done on the basis of measurement of antenna parameters such as Return Loss, Voltage Standing Wave Ratio (VSWR) , Gain, Directivity, Radiation of antenna using HFSS simulation software.

5. ANTENNA DESIGN AND SIMULATION

5.1. Reference Antenna

A dual band microstrip patch antenna is designed in HFSS simulation software as shown in Figure 5.1 with reference to the dimension mentioned in Figure 5.1 as a reference antenna.

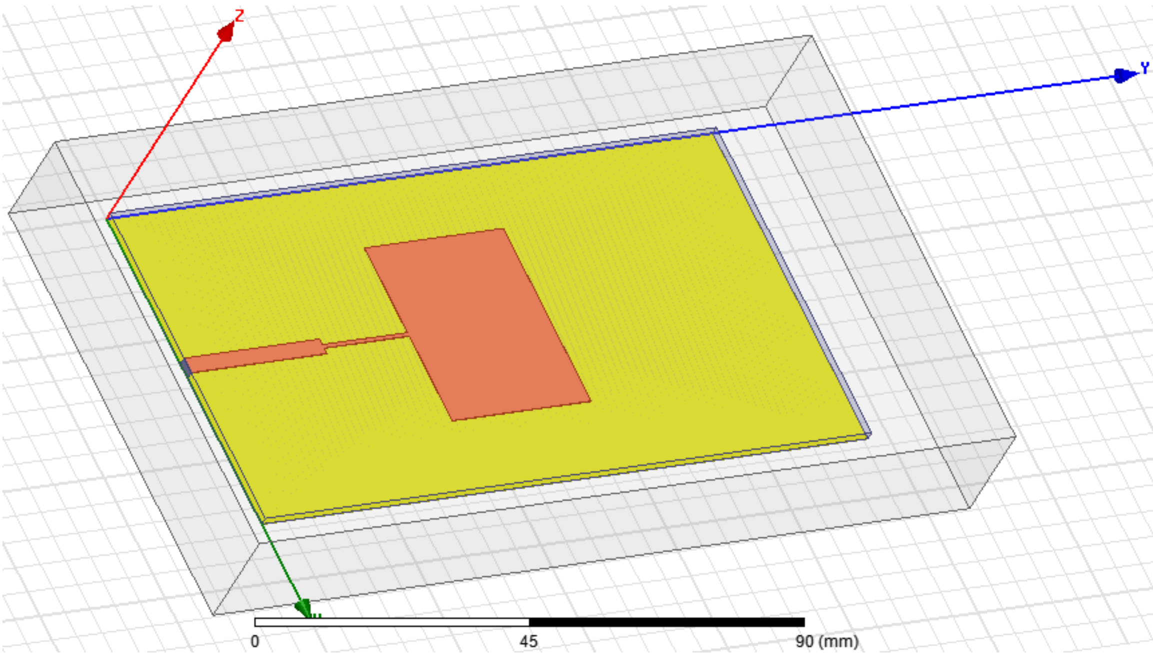


Figure 5.1: Reference Antenna

The S_{11} parameter of reference antenna obtained from simulation is shown in graph in Figure 5.2. Graph shows that the antenna can be used for dual band with Return Loss -14.65 dB at resonance frequency 2.4 GHz and that of -13.04 dB at 4.7 GHz. Also there is one additional band at resonance frequency 3.8 GHz which is not taken because the return loss at that frequency is less than -10 dB and cannot applicable due to much loss. But the value of return loss can be reduced using optimization at that band.

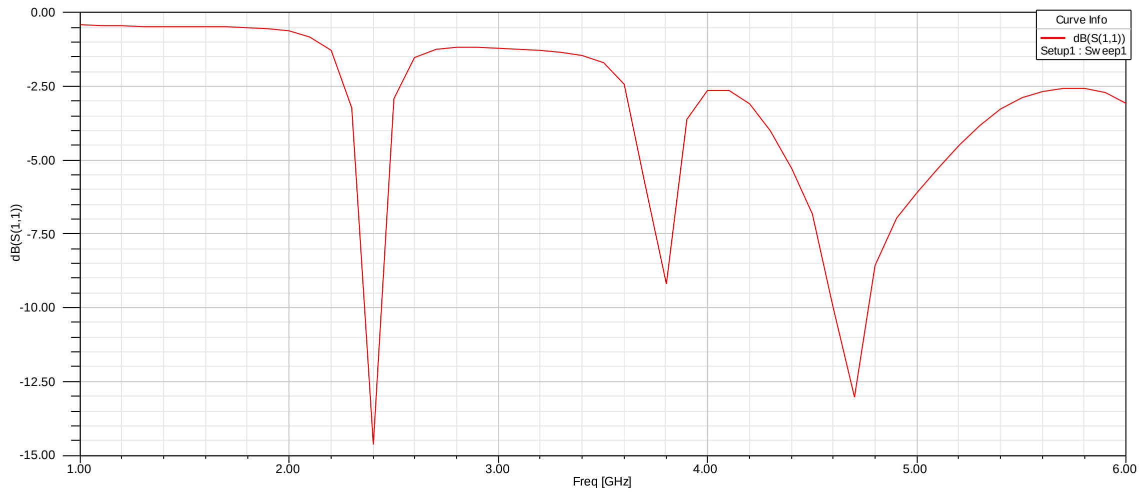


Figure 5.2: S parameter of reference antenna

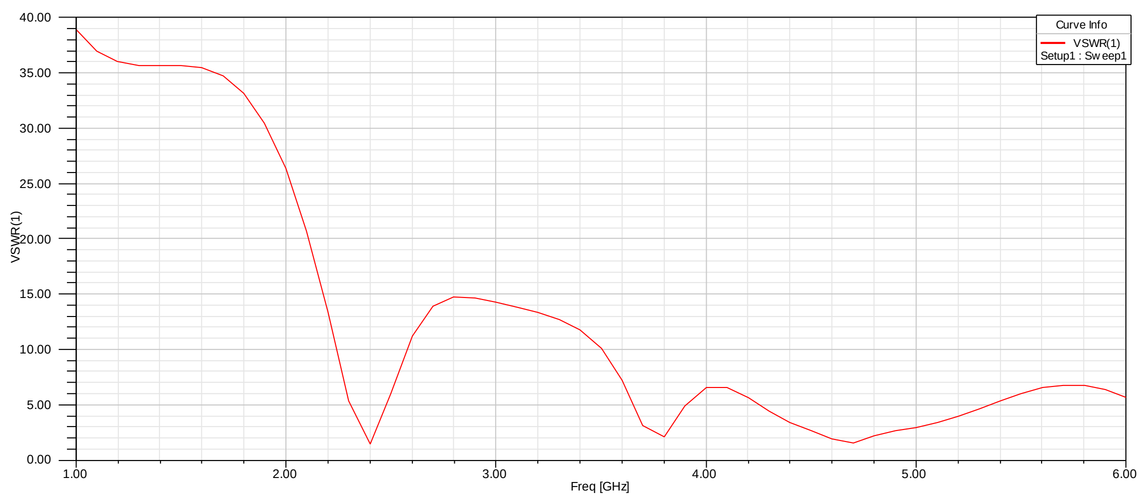
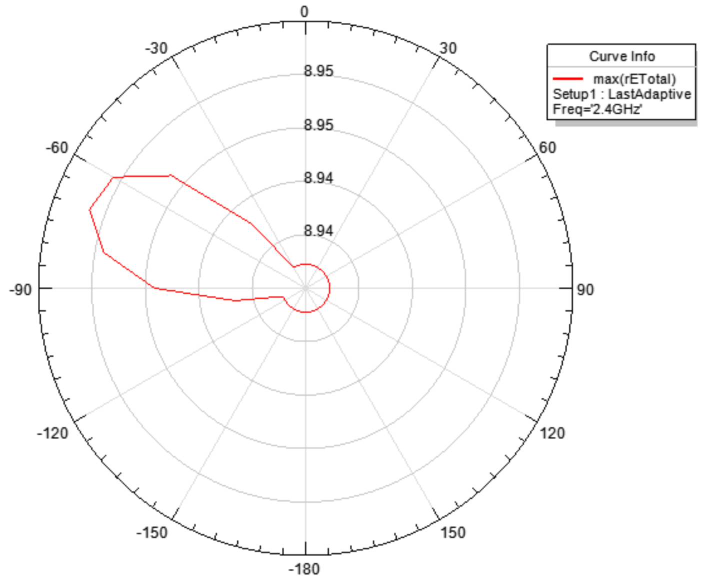
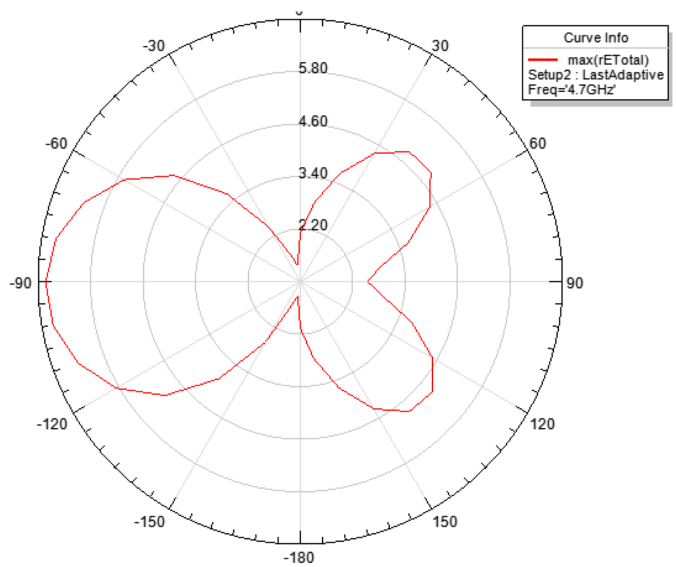


Figure 5.3: VSWR of reference antenna

The VSWR of reference antenna is 1.45 at resonance frequency 2.4 GHz ant that of 1.57 at 4.7 GHz as shown in Figure 5.3. The radiation pattern of reference antenna operating at 2.4 GHz frequency as shown in Figure 5.4. The value of return loss is lowest where value of VSWR is also lowest. Typical value of VSWR is on range of 1 to 2. The antenna with voltage standing wave ratio closed to 1 has better performance because of most of incident power is radiated and signal reflection reduced.



(a)



(b)

Figure 5.4: Radiation pattern of reference antenna at (a) 2.4 GHz (b) 4.7 GHz

The radiation pattern shown in Figure 5.4 (a) shows the directional radiation pattern with half power beam width around 40 degree with small back lobe opposite to main lobe. The figure 5.4 (b) shows the radiation pattern of reference antenna at frequency 4.7 GHz which consist of two side lobes and main lobe with half power beam width of near 80 degree. The excessive side lobe radiation wastes the energy and may cause interference to other equipment.

5.2 Dual Band Antenna with Single Swastika Slot

The design of dual band antenna with single swastika slot is shown in Figure 5.5. The slot of swastika shape of size 8 mm x 8 mm and slot width 1mm is made over the patch of reference antenna and its performance is observed by simulation.

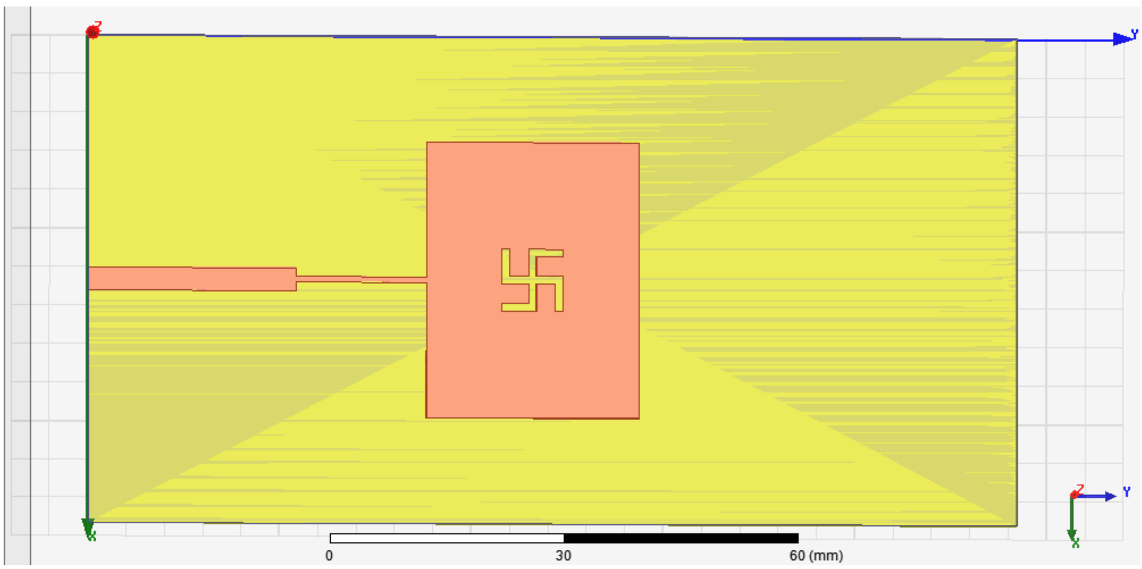


Figure 5.5: Design of microstrip antenna with single swastika slot

The dual band microstrip antenna with single swastika slot can be operate at two resonance frequencies 2.3 GHz and 4.6 GHz as shown in Figure 5.6 and the return loss and VSWR for respective resonance frequencies are -17.46 dB, -19.97 dB and 1.31, 1.22 respectively. This shows that both value of return loss and VSWR is improved in antenna with swastika slot.

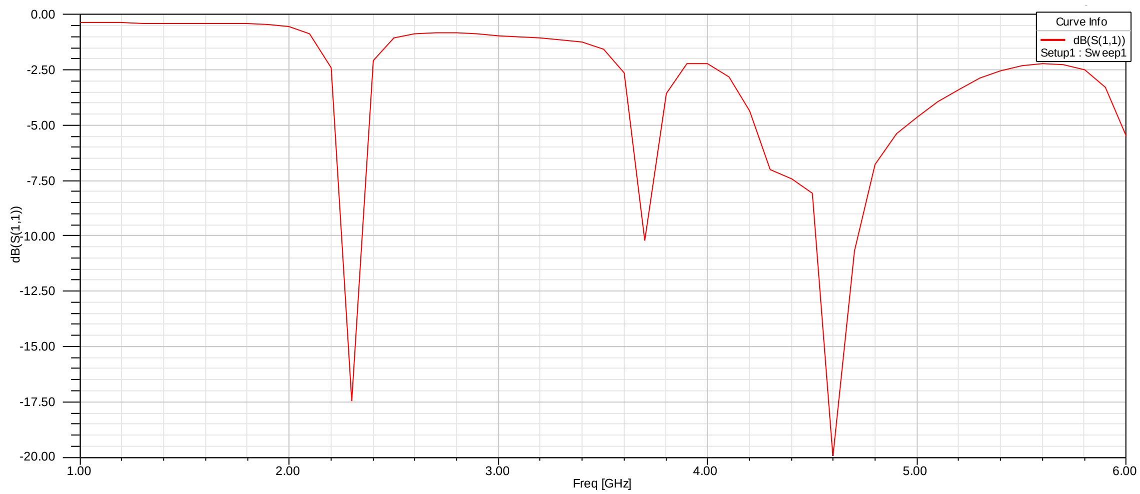


Figure 5.6: S parameter of antenna with single swastika slot

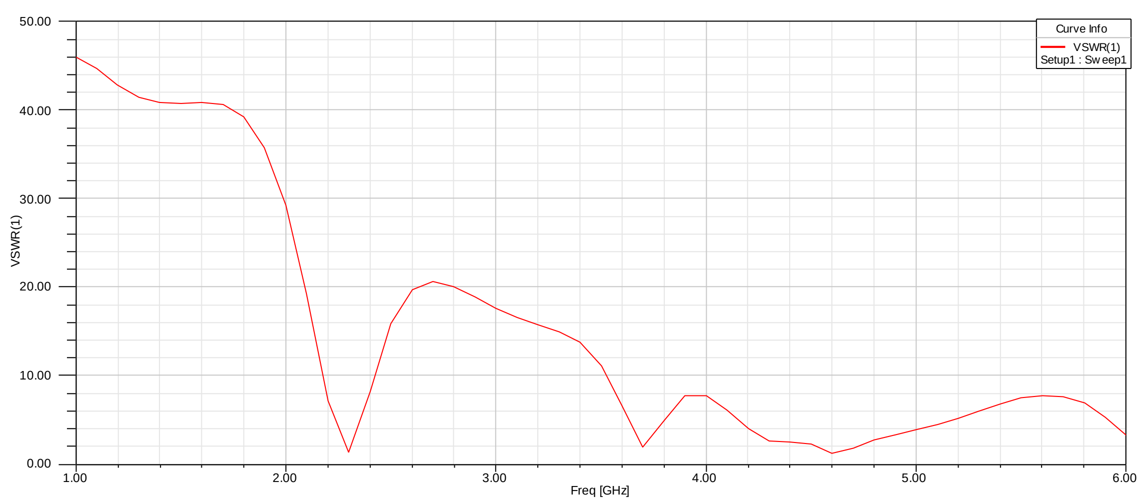
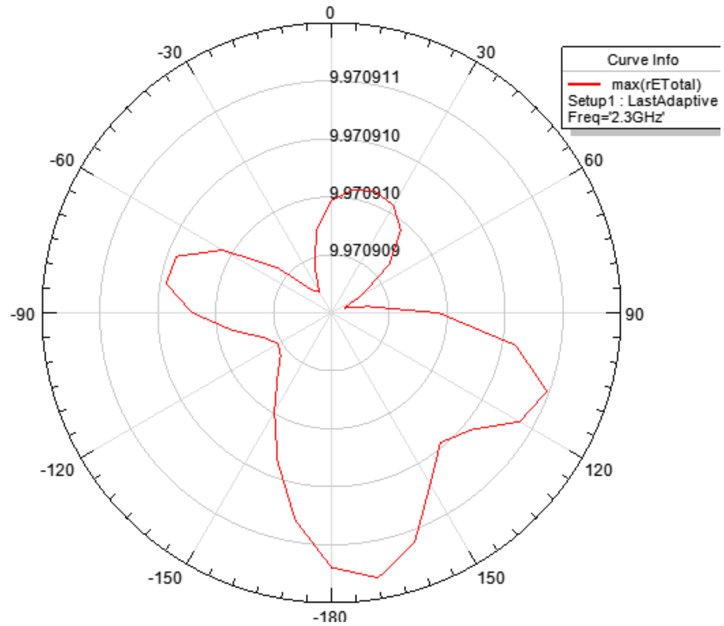
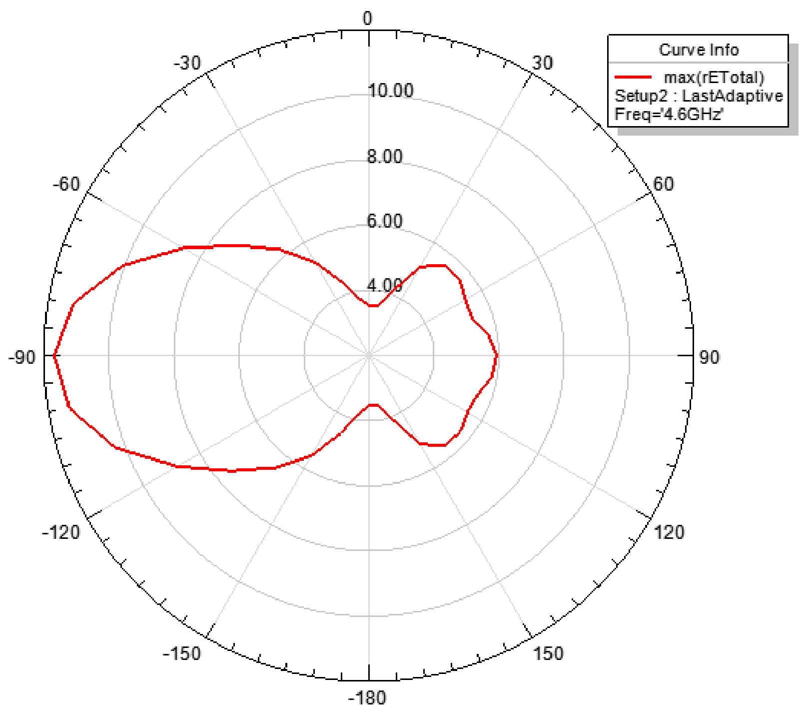


Figure 5.7: VSWR of antenna with single swastika slot

The additional band at resonance frequency 3.7 GHz also appear as shown in Figure 5.6. The return loss is -10.4 dB at that frequency and can be include in optimization to make triple band antenna. This is because of the self-similarity property of fractal shape as the can make support to oscillate at multiple frequency.



(a)



(b)

Figure 5.8: Radiation pattern of antenna with single swastika slot at (a) 2.3 GHz (b) 4.6 GHz

The radiation pattern of antenna with swastika slot is shown in Figure 5.8.The radiation pattern is directional with major lobe with beam width around 80 degree. But the side lobes are also found quite large while operating at 2.4 GHz frequency which decreases the radiation performance of antenna.

5.3 Dual Band Antenna with Fractal Swastika Slot

The dual band antenna is designed by locating a stage 2 fractal swastika slot structure at the middle of the reference antenna. The designed antenna consist of stage 2 fractal swastika shape of dimension 18 mm × 18 mm and slot width D of 0.5 mm as shown in Figure 5.9.

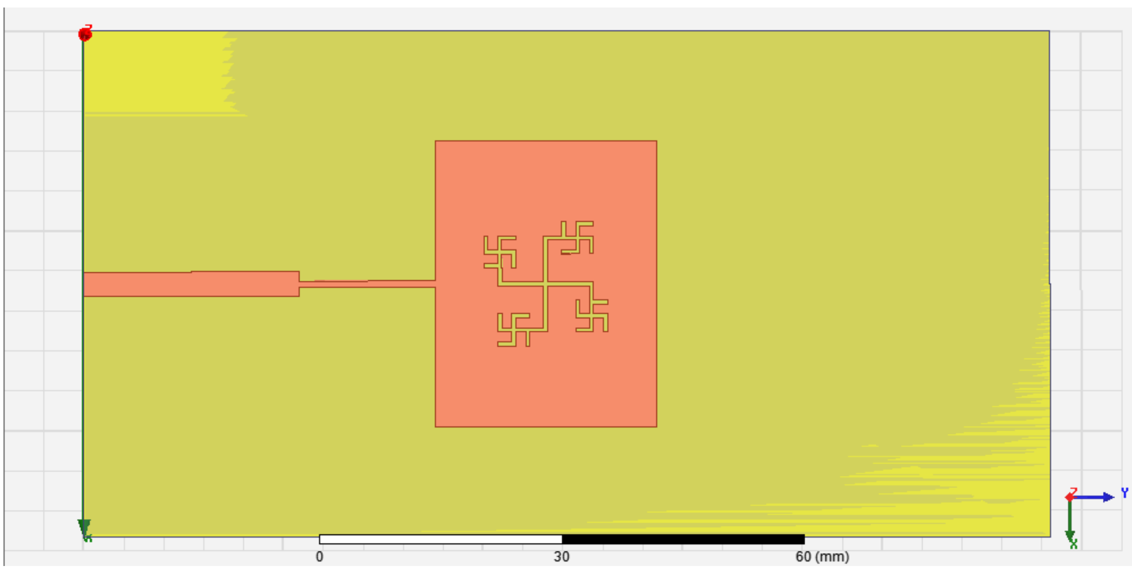


Figure 5.9: Design of purposed antenna

The S parameter, VSWR, Radiation pattern of antenna shown in Figure 5.9 are observed using simulation of this antenna in HFSS and are shown in the graph plotted as shown in Figure 5.10-5.13.

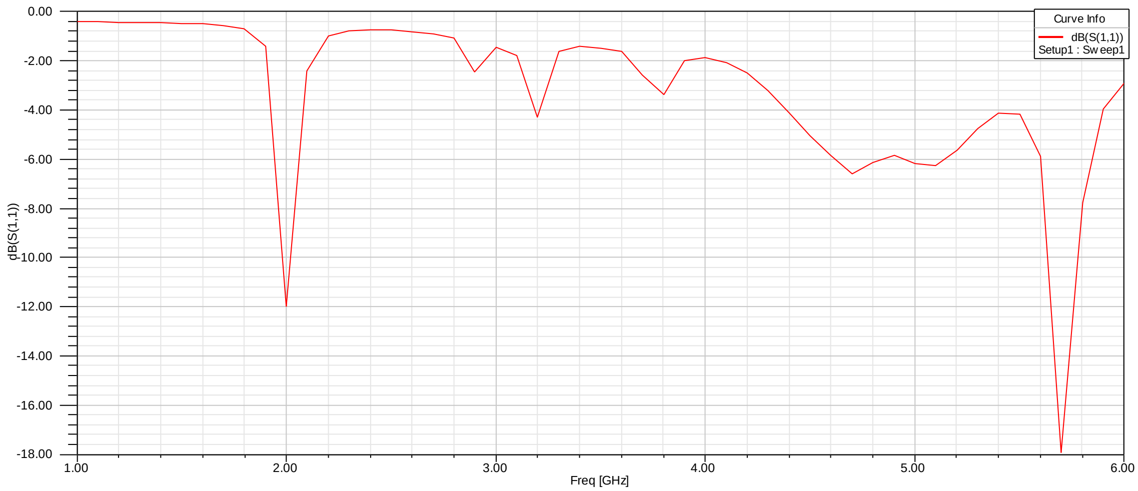


Figure 5.10: S parameter of purposed antenna without optimization

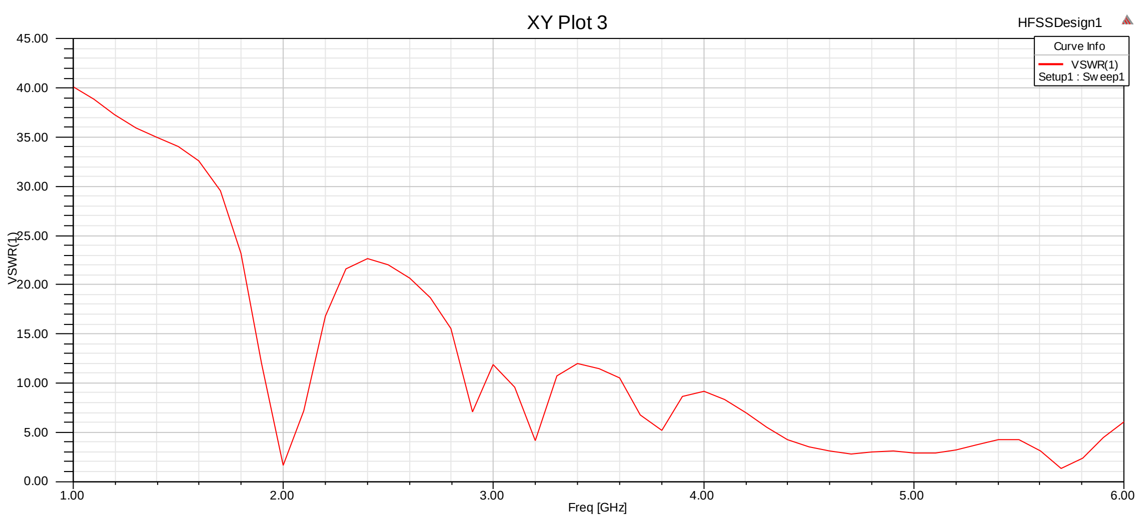
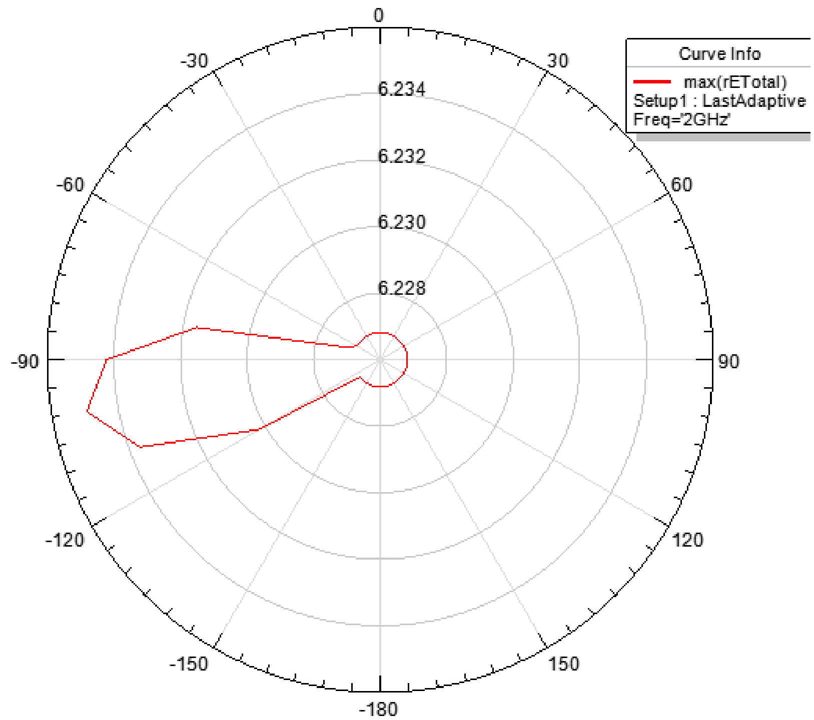
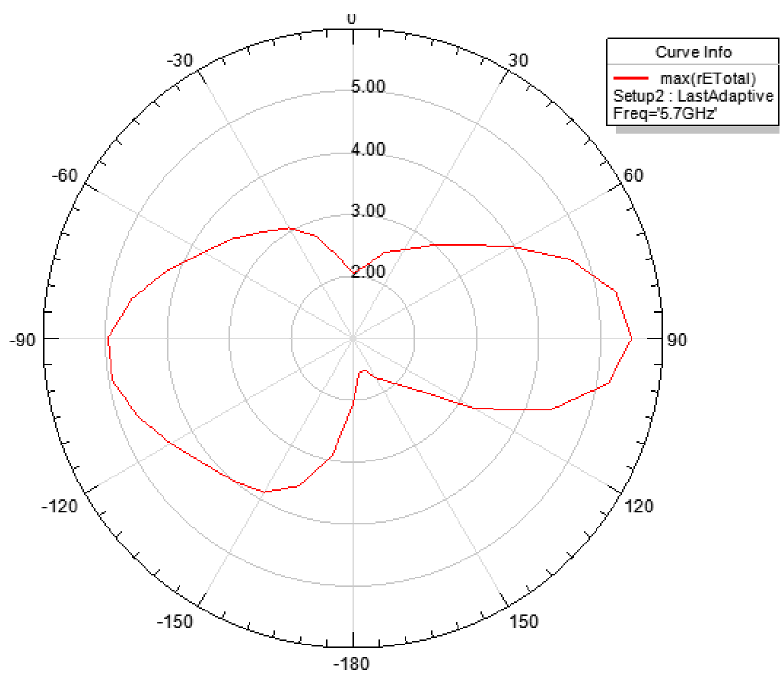


Figure 5.11: VSWR of purposed antenna without optimization



(a)



(b)

Figure 5.12: Radiation pattern of purposed antenna without optimization at (a) 2 GHz (b) 5.7 GHz

The size of fractal slot is taken randomly. Due to the change in effective patch area, the resonance frequencies are shifted to 2 GHz and 5.7 GHz. The return loss and VSWR of antenna are found to be -12 dB S11 -18 dB and 1.67 S11 1.29 respectively at resonance frequencies 2 GHz and 5.7 GHz. This result is obtained from the purposed antenna without optimization and is expected to be improved after performing optimization using genetic algorithm.

5.4 Optimized Dual Band Antenna with Fractal Swastika Slot

The microstrip antenna with stage 2 fractal swastika slot as shown in Figure 5.9 is optimized using genetic algorithm. The optimization of return loss is done by varying length and width of fractal swastika slot. The optimized value is found at slot with dimension 8 × 8 mm and width 0.42 mm where return loss is found to be - 20.16 dB and - 20.62 dB.

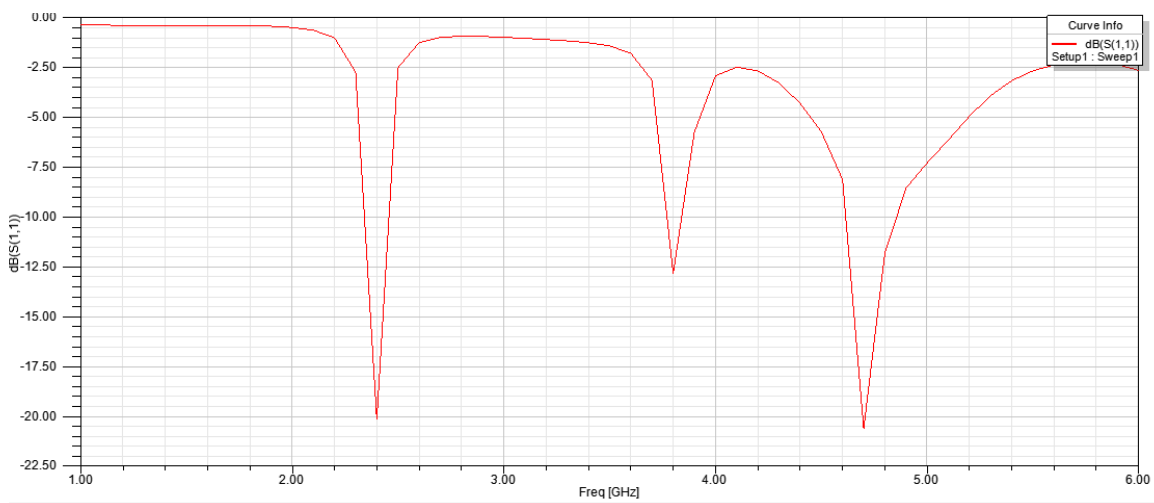


Figure 5.13: S parameter of purposed antenna after optimization

The additional band at resonance frequency 3.7 GHz also appear as shown in Figure 5.13. The return loss is -13 dB at that frequency and can be used as triple band antenna. This is because of the self-similarity property of fractal shape as the can make support to oscillate at multiple frequency. But the bandwidth of the antenna at that frequency is lower as compared to the that of other frequency band.

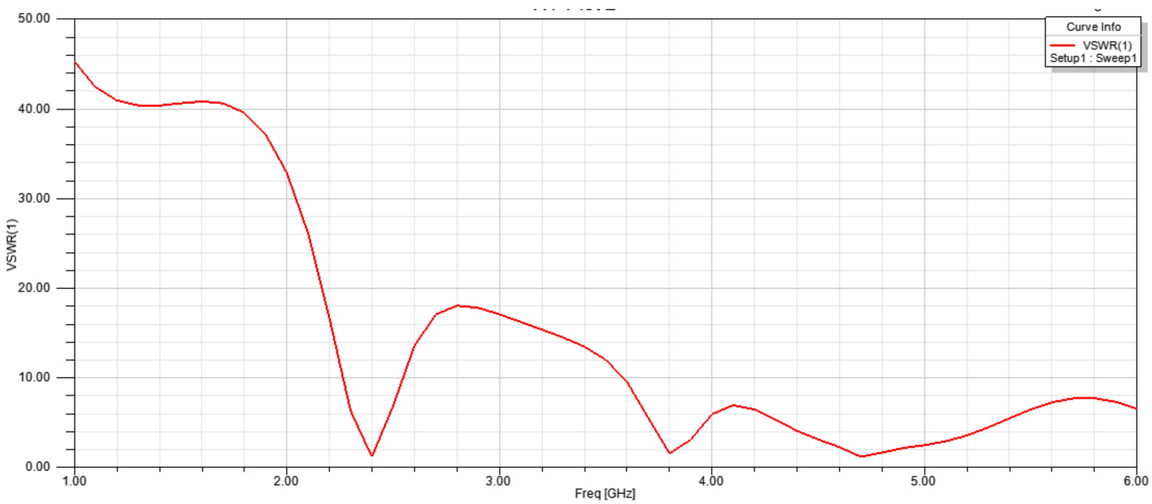
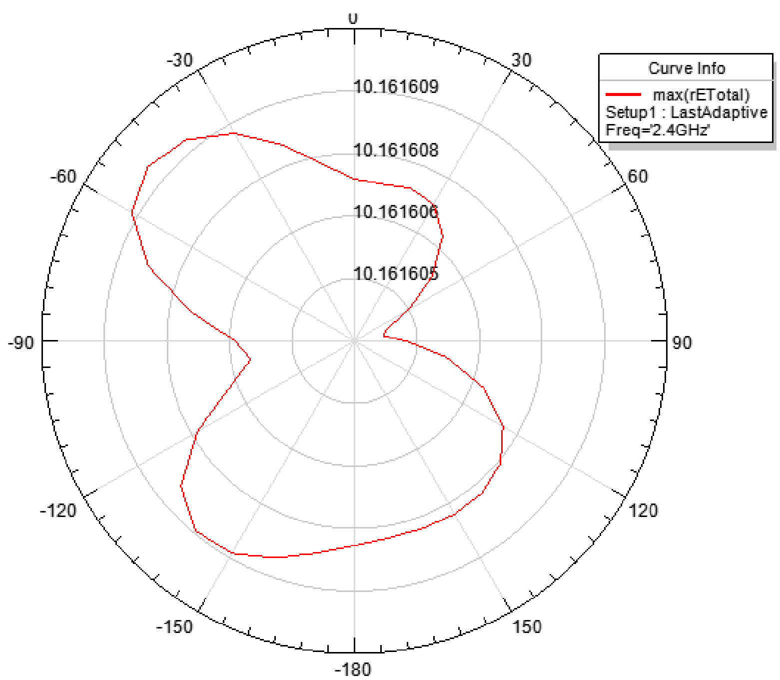
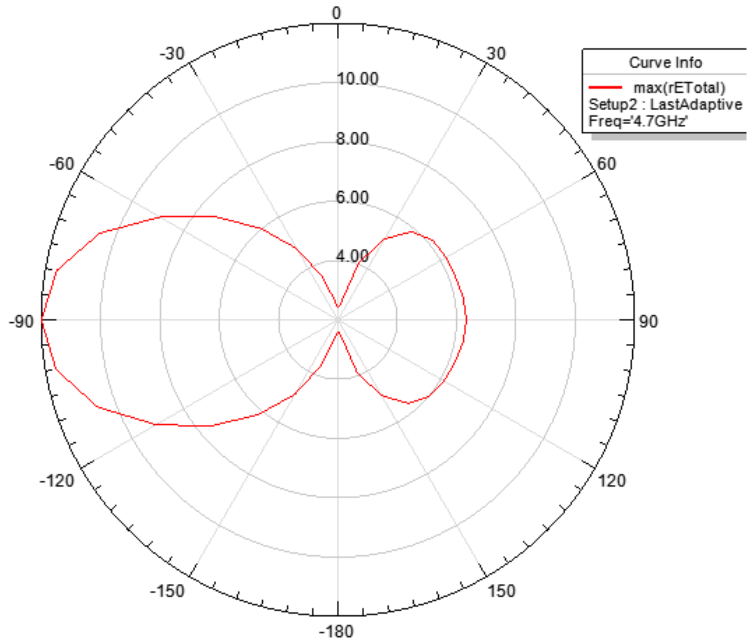


Figure 5.14: VSWR of purposed antenna after optimization

The VSWR of antenna after optimization is found to be 1.21 and 1.20 at resonance frequency 2.4 and 4.7 GHz respectively.



(a)



(b)

Figure 5.15: Radiation pattern of purposed antenna after optimization at (a) 2.4 GHz (b) 4.7 GHz

The radiation pattern of purposed antenna is shown in Figure 5.15. The radiation pattern observed at operating frequency 2.4 GHz is found omnidirectional with beam width about 90 degree and the directional radiation pattern is observed at 4.7 GHz operating frequency. The side lobe is decreased as compared to the radiation pattern of reference antenna shown in Figure 5.4 which reduces the energy loss and interference due to the unwanted radiation on other than the major lobe.

6. RESULTS AND DISSCUSSION

A dual band rectangular patch antenna with microstrip line feed is designed as a reference antenna to compare its performance with the purposed dual band microstrip antenna with fractal swastika shaped slot. The reference antenna is found to be operate at two resonance frequency 2.4 GHz and 4.7 GHz with Return Loss and VSWR of -14.65 dB and 1.45 at resonance frequency 2.4 GHz and that of -13.04 dB and 1.57 at 4.7 GHz respectively. The dual band microstrip antenna with fractal swastika slot with initial dimension of 18 mm × 18 mm and slot width 0.5 mm is designed in HFSS software and the optimization of antenna by varying slot size is done by using genetic algorithm. The optimization is achieve at slot dimension of 8 × 8 mm and slot width of 0.42 mm. The return losses of antenna after optimization are found to be - 20.16 dB and -20.62 dB at resonance frequency 2.4 GHz and 4.7 GHz respectively.

6.1 The effect of changing slot shape

The effect of changing slot shape and size can be observed from Table 6.1.

Table 6.1 Comparison of antenna parameters with different slot shape

Shape of slot	Without Slot		Stage 1 fractal swastika slot		Stage 2 fractal swastika slot (Before Optimization)		Stage 2 fractal swastika slot (After Optimization)	
Slot Dimension	-		L = 8 mm , D = 1 mm		L = 18 mm , D = 0.5 mm		L = 8 mm , D = 0.42 mm	
Resonant Frequencies (GHz)	2.4	4.7	2.3	4.6	2.0	5.7	2.4	4.7
Frequency Band (GHz)	2.36-2.44	4.6-4.76	2.25-2.35	4.5-4.7	1.98-2.02	5.63-5.77	2.34-2.46	4.61-4.85

Return Loss (dB)	-14.64	-13.04	-17.46	-19.97	-12.02	-17.92	-20.16	-20.61
VSWR	1.45	1.57	1.31	1.22	1.66	1.29	1.21	1.20
Bandwidth (MHz)	80	160	100	200	40	140	120	240
Gain (dBi)	1.38	0.87	1.69	2.3	0.69	0.9	1.74	2.4
Directivity (dBi)	2.59	2.63	4.5	8.3	1.9	3.8	4.1	7.8

The result shows that the performance of purposed antenna with stage 2 swastika fractal slot after optimization has been improved as compared to the reference antenna. The return loss is reduced by 37%. The VSWR is reduced by 0.24. The bandwidth is increased by 50% as compared to reference antenna. Also the gain of purposed antenna is improved by 26%. But the efficiency of antenna was found quite low. So the purposed antenna is suitable to reduce the return loss and increase the bandwidth in the indoor wireless applications.

The purposed antenna can be operated in dual frequency band because of the self-similarity property of the fractal swastika slot and can be make oscillate at multiple frequencies. Also the improved in radiation properties is because of the shape of slot, few portion of patch of antenna acts as both radiator and reflector. So that the side lobes in radiation pattern of reference antenna in Figure 5.4 (b) is reduced in purposed antenna shown in Figure 5.16 (b). The maximum spherical polarization ratio of reference antenna shown in figure 5.5 consist of many side lobes and widen which is improved in purposed antenna shown in Figure 5.17 such that the side lobes are disappeared and the polarization is sharpened.

According to the various wireless standard shown in Table 3.1, the purposed antenna can be applicable for International Mobile Telecommunication (IMT), WLAN, Bluetooth, WiMAX applications.

6.2 The effect of changing slot dimension

The effect of changing slot dimension in stage 1 swastika slot is observed by varying the value of slot length L which is equal to its width W and the thickness of slot D. The observation is done in HFSS simulator software by observing the value of S parameter at frequency 2.4 GHz and 4.7 GHz for different values of L and D which is shown in Table 6.2.

Table 6.2: The effect of changing slot dimension for frequency 2.4 GHz

	S_{11} parameter at 2.4 GHz in dB			
D (thickness of Slot) in mm	Length 8 mm	Length 12 mm	Length 16 mm	Length 20 mm
0.1	-13.04	-3.09	-1.13	-4.36
0.2	-8.47	-1.76	-0.98	-2.35
0.4	-6.76	-1.43	-0.85	-1.74
0.6	-5.42	-1.41	-0.82	-1.6
0.8	-4.87	-1.24	-0.82	-0.8
1	-4.11	-1.19	-0.76	-0.72

The comparison of value of S parameter for different length and thickness of slot measured at frequency 2.4 GHz are shown in Figure 6.1. The values of S_{11} parameter is found in decreasing order while increasing the slot size. This is because of the increment of the slot area make decrease in the area of patch. The resonance frequency depends on the effective patch length and width [15]. So the frequency of oscillation is shifted to another frequency, so that the Return Loss for resonant frequency is minimum and comparatively higher in other frequency.

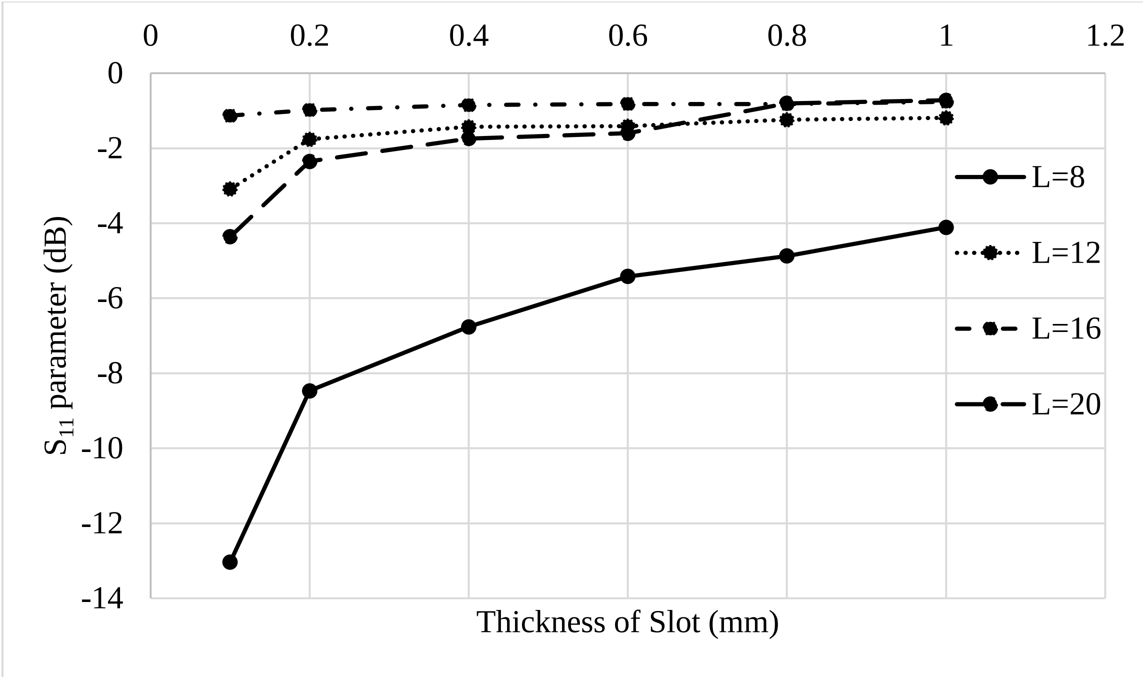


Figure 6.1: S_{11} parameter vs. Thickness of slot (D) for different value of Length at frequency 2.4 GHz

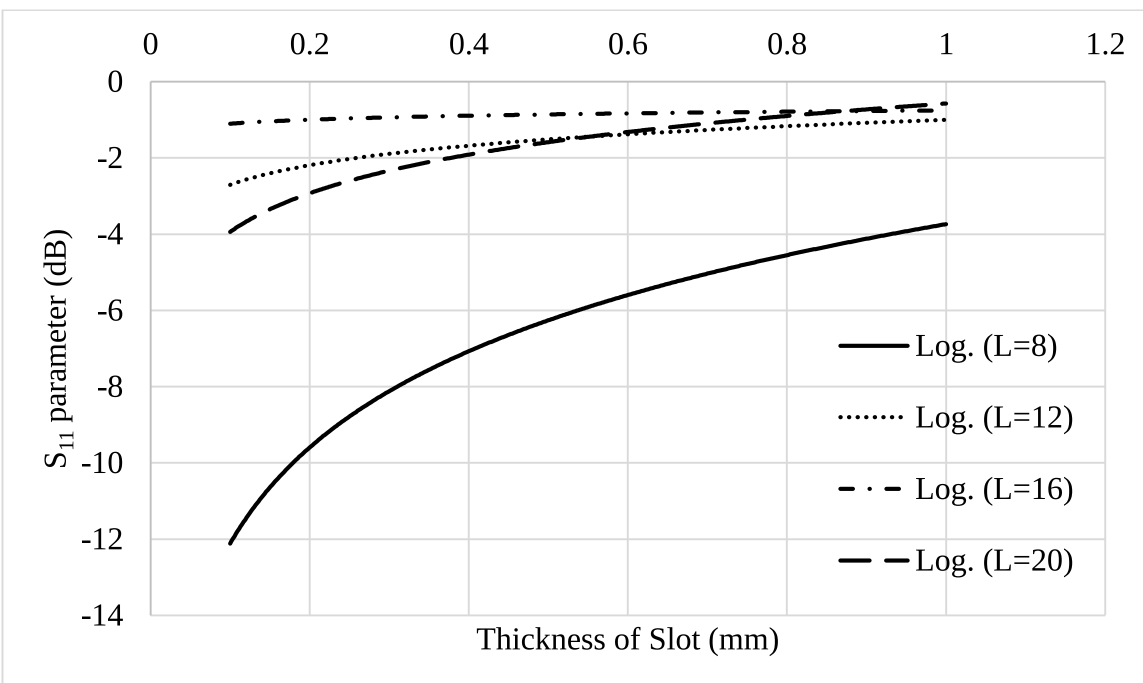


Figure 6.2: Trending Plot for graphs of Figure 6.1

The trending of plots shown in Figure 6.2 are logarithmic and the estimated formulae using the Microsoft Excel for the S parameter for different length and R squared value are mentioned in equation 6.1-6.4.

$S_{11,\, fr = 2.4\, GHz,\, L = 8} = 3.1714\, Ln\, (D) – 4.005,$ $R^2 = 0.9092$ (6.1)

$S_{11,\, fr = 2.4\, GHz,\, L = 12} = 0.7373\, Ln\, (D) – 1.0032,$ $R^2 = 0.824$ (6.2)

$S_{11,\, fr = 2.4\, GHz,\, L=16} = 0.1521\, Ln\, (D) – 0.7524,$ $R^2 = 0.9565$ (6.3)

$S_{11,\, fr = 2.4\, GHz,\, L = 20} = 1.4631\, Ln\, (D) – 0.572,$ $R^2 = 0.9277$ (6.4)

From equation 6.1-6.4, the value of intercepts and slope are varied due to variation in length of slot. The dependency on length is estimated by polynomial equation using Microsoft Excel and the purposed equation to find the value of S_{11} parameter at resonance frequency (fr) 2.4 GHz is shown in Equation 6.5 and all the design parameters such as rectangular patch length, patch width, length of feeding line, substrate material and patch material are kept constant as mentioned in reference antenna in Chapter 4.

$$S_{11,\, fr = 2.4GHz} = (0.0585\, L^2 - 1.7812\, L + 13.679)\, Ln\, (D) – 0.0441\, L^2 + 1.4981\, L – 13.034 \quad (6.5)$$

Table 6.3: The effect of changing slot dimension for frequency 4.7 GHz

	S_{11} parameter at 4.7 GHz in dB			
D (thickness of Slot) in mm	Length 8	Length 12	Length 16	Length 20
0.1	-13.34	-7.95	-7.37	-7.17
0.2	-12.45	-5.3	-6.21	-6.79
0.4	-12.02	-4.48	-5.99	-6.69
0.6	-11.61	-4.38	-5.97	-5.42
0.8	-11.54	-4.1	-5.32	-5.12
1	-10.83	-3.89	-3.61	-4.93

The comparison of value of S parameter for different length and thickness of slot measured at frequency 4.7 GHz are shown in Figure 6.3. The pattern of changing the value of S parameter while varying the value of patch length and width shown in Figure 6.3 looks similar to the plot shown in Figure 6.1 for 2.4 GHz but the slope and intercept value of curve are different.

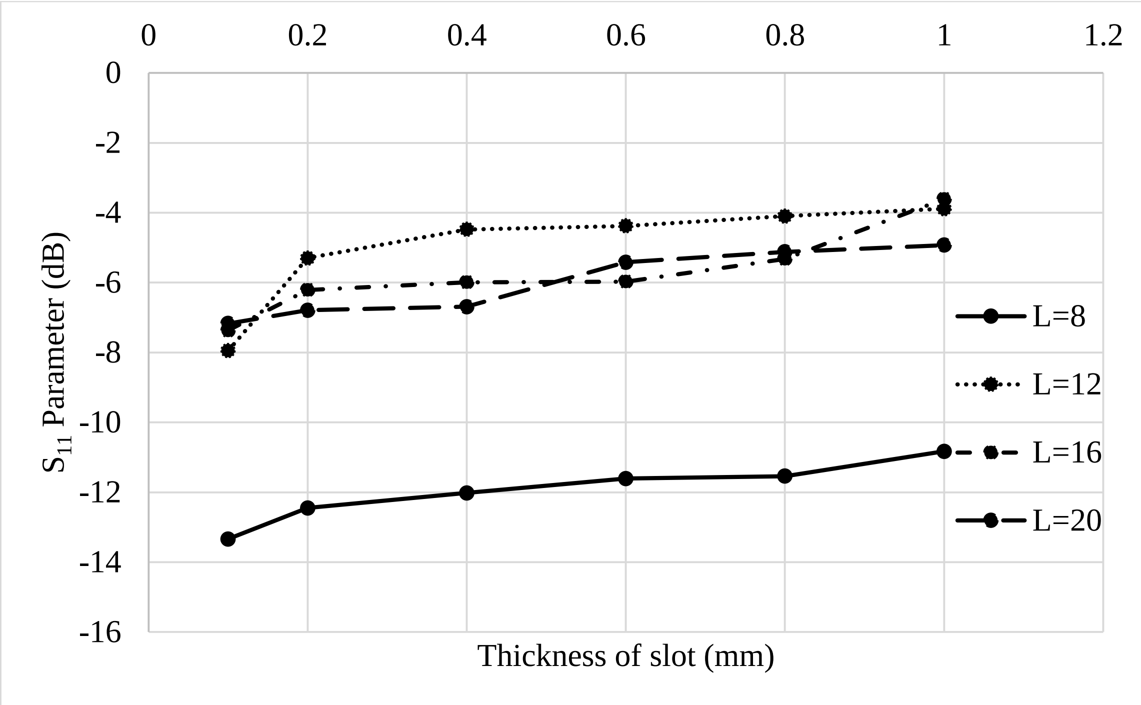


Figure 6.3: S_{11} parameter vs. Thickness of slot (D) for different value of Length at frequency 4.7 GHz

The effect of changing slot size while operating at 2.4 GHz shown in Figure 6.1 is quite similar to the effect of changing slot size at operating frequency 4.7 GHz as the smallest size of slot results lowest return loss. The increment of slot size results the change in shape and size of patch which changes the resonance frequency as it depends on the effective patch width.

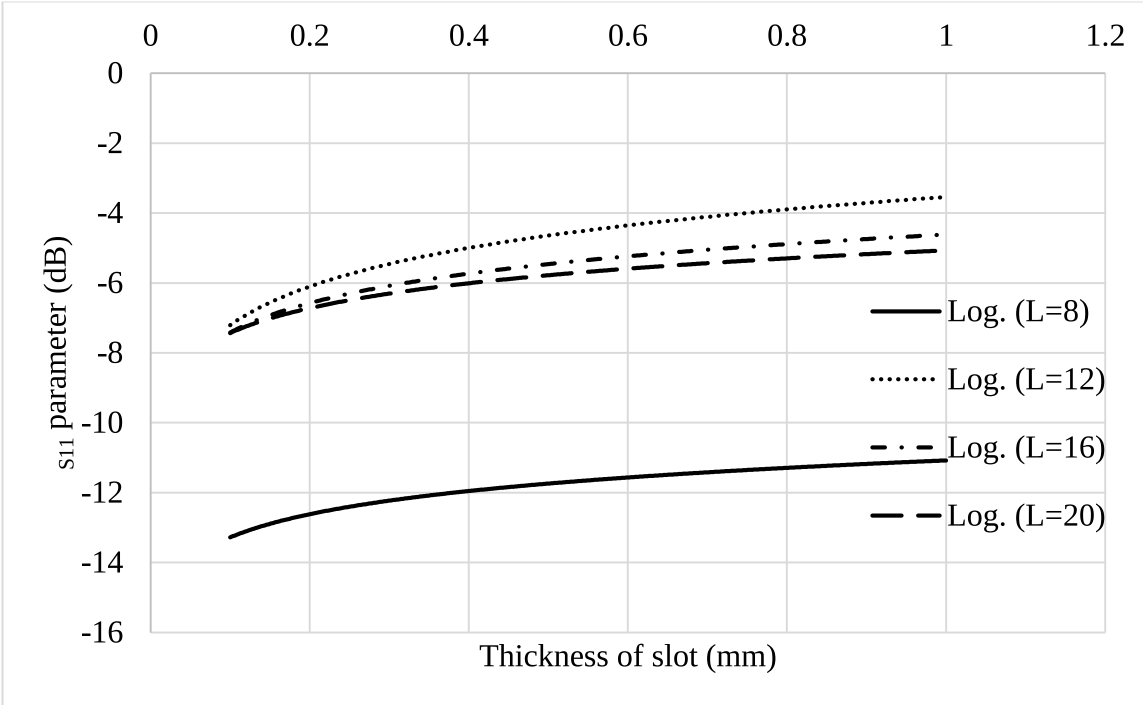


Figure 6.4: Trending Plot for graphs of Figure 6.3

The trending of plots shown in Figure 6.4 are logarithmic and the estimated formulae using the Microsoft Excel for the S parameter for different length and R squared value are mentioned in equation 6.6-6.9.

$S_{11,\ fr\ =\ 4.7\ GHz,\ L\ =\ 8} = 0.9575\ Ln\ (D) - 11.077,\qquad R^2 = 0.9568\qquad (6.6)$

$S_{11,\ fr\ =\ 4.7\ GHz,\ L\ =\ 12} = 1.5926\ Ln\ (D) - 3.5403,\qquad R^2 = 0.858\qquad (6.7)$

$S_{11,\ fr\ =\ 4.7\ GHz,\ L\ =\ 16} = 1.2184\ Ln\ (D) - 4.6155,\qquad R^2 = 0.7486\qquad (6.8)$

$S_{11,\ fr\ =\ 4.7\ GHz,\ L\ =\ 20} = 1.0277\ Ln\ (D) - 5.0672,\qquad R^2 = 0.8692\qquad (6.9)$

From equation 6.6-6.9, the value of intercepts and slope are varied due to variation in length of slot. The dependency on length is estimated by polynomial equation using Microsoft Excel and the purposed equation to find the value of S_{11} parameter at frequency 4.7 GHz is shown in Equation 6.10 and all the design parameters such as rectangular patch length, patch width, length of feeding line, substrate material and patch material are kept constant as mentioned in reference antenna in Chapter 4.

$$S_{11,\, fr = 4.7GHz} = (-0.016\, L^2 + 0.4597\, L - 1.8246)\, Ln\,(D) - 0.1248\, L^2 + 3.9188\, L - 33.977 \quad (6.10)$$

6.3 Validation of Equations

The equation 6.5 and 6.10 are validated by comparing the value of S_{11} parameter for different ten values of length and thickness of slot. The analytical values and simulated values obtained from different observations are shown in Table 6.4.

Table 6.4: Observation table for validation

	Length of slot	Thickness of slot	Analytical Values		Simulated Values	
Observation No.	L (mm)	D (mm)	$S_{11,\, fr=2.4\, GHz}$ in dB using Equation (6.5)	$S_{11,\, fr= 4.7\, GHz}$ in dB using Equation (6.10)	$S_{11,\, fr=2.4\, GHz}$ in dB	$S_{11,\, fr= 4.7\, GHz}$ in dB
1	8	0.15	-9.89	-12.18	-10.46	-13.29
2	8	0.9	-4.20	-10.70	-4.46	-11.6
3	9	0.1	-8.62	-11.15	-8.90	-11.34
4	9	0.7	-3.97	-9.18	-3.51	-9.65
5	11	0.2	-3.76	-8.05	-3.93	-8.95
6	13	0.65	-1.18	-4.74	-1.07	-4.29
7	14	0.3	-0.95	-5.35	-1.07	-5.29
8	15	0.5	-0.57	-4.29	-0.56	-4.00
9	17	0.6	-0.46	-4.12	-0.48	-4.82
10	19	0.5	-1.15	-5.35	-1.418	-4.75
11	5	0.5	-10.96	-17.55	-12.96	-16.73
12	22	0.1	-7.88	-9.42	-6.73	-8.07

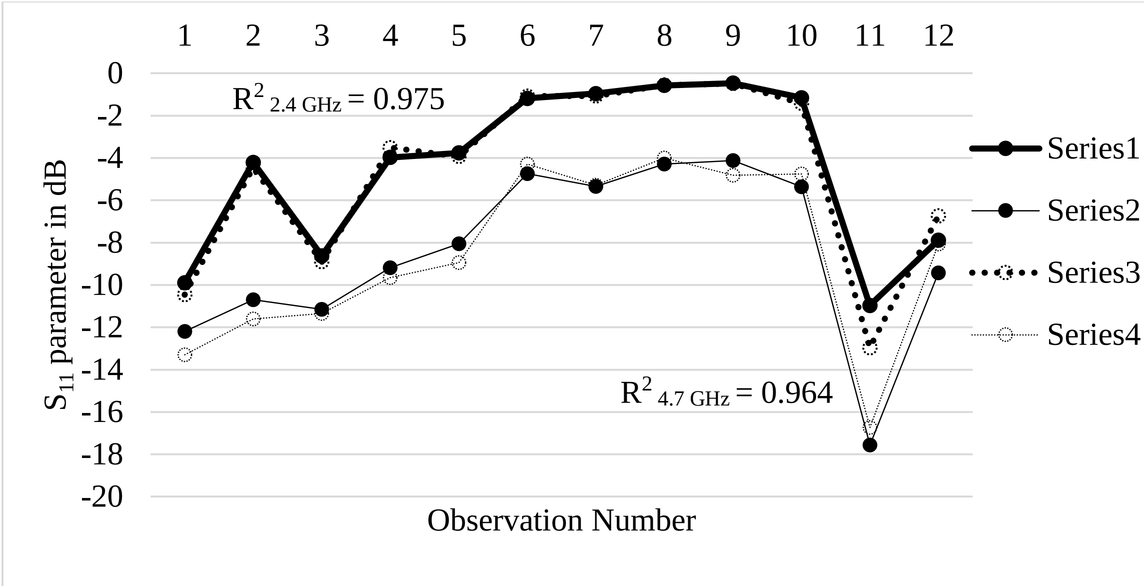


Figure 6.5: Analytical vs. Simulated values of S_{11} Parameter for different values of length and thickness of slot

In Figure 6.5, Series1 represents the graph for Analytical values of S_{11} parameter at 2.4 GHz frequency, Series2 represents the graph for Analytical values of S_{11} parameter at 4.7 GHz frequency, Series3 represents the graph for Simulated values of S_{11} parameter at 2.4 GHz frequency, Series4 represents the graph for Analytical values of S_{11} parameter at 4.7 GHz frequency.

The R squared value i.e. coefficient of determination for the data at 2.4 GHz is found 0.975 and that for 4.7 GHz is found 0.964. This concludes that the analytical values of S_{11} parameters calculated using formula are much closed to the respective values observed from simulation.

6.4 Analysis

The results shows that the Return Loss of reference antenna -14.64 dB, -13.04 dB at resonance frequency 2.4 GHz and 4.7 GHz respectively. The Peano-Gosper fractal slot of length 24 mm and thickness 0.12 mm optimized by PSO was introduced to reference antenna by Kuhirun [4] and improved Return Loss are -15.02 dB and -16 dB at resonance frequency 2.45 GHz and 5 GHz respectively. The fractal Swastika slot of length 8 mm and thickness 0.42 mm optimized using genetic algorithm is introduced to reference antenna in this research and improved return loss are -20.16 dB and -20.61 dB for resonance frequency 2.4 GHz and 4.7 GHz respectively. The radiation pattern of purposed antenna is improved as the size of side lobes are reduced which helps to reduce the power loss and interference on other devices due to unwanted radiation. The gain and directivity of reference antenna was 1.38 dBi and 2.59 dBi while operating at 2.4 GHz frequency respectively and improved to 1.74 dBi and 4.1 dBi respectively in purposed antenna.

The dual band microstrip antenna with fractal swastika slot is designed and the size of slot is optimized by using genetic algorithm. The performance parameters of purposed antenna and reference antenna are compared and analyzed. The effect of changing the slot length and thickness is observed and the effect on S parameter at constant operating frequency is formulated by Equation 6.5 and 6.10 at all other design parameters such as patch size, patch width, patch material, dimension of feed line, length, width and material of substrate constant. Hence the objective of this thesis is achieved.

7. CONCLUSION

The dual band microstrip patch antenna with fractal swastika slot is designed and simulated in HFSS simulation software. This antenna can be operate around 2.4 GHz and 4.7 GHz frequency. Introducing of fractal swastika slot improves the radiation properties of antenna in terms of return loss, bandwidth and gain. The effect of changing slot shape and size is observed by varying the length and thickness of swastika slot. The effect of changing size of slot on S parameter is observed and formulated. The relation of value of S parameter is found natural logarithmic of thickness at constant length and while varying length, the slope and intercept of the curve changed. The antenna is applicable for different wireless technologies such as IMT, WLAN, Bluetooth and WiMAX. The performances of purposed antenna are improved in terms of return loss, VSWR, bandwidth and gain whose values are -20.16 dB, 1.21, 140MHz and 1.74 dBi respectively for resonance frequency 2.4 GHz and -20.61 dB, 1.20, 240 MHz and 2.4dBi respectively for resonance frequency 4.7 GHz. The purposed antenna can be applicable for different wireless applications near around 2300-2500 MHz and 4600-4900 MHz frequency bands.

The microstrip patch antenna with fractal swastika slot is designed and simulated in High Frequency Structural Simulator software and optimized using genetic algorithm. This antenna can be further optimize by using different algorithms for optimization. Also three or more stages of fractal swastika shape or new shape of slot can be implemented on antenna design as a future work. Future work will concentrate on how to tackle with size and performance of this type of antenna. Triple band with high gain will be a good idea to continue studies in this field.

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APPENDIX: DESIGN SUMMARY IN HFSS